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NASA Conference Publication 6

COMPLETED  
ORIGINAL

# Application of Remote Sensing to the Chesapeake Bay Region

Volume 2 - Proceedings

A conference held at  
Coolfont Conference Center  
Berkeley Springs, West Virginia  
April 12-15, 1977



NASA Conference Publication 6

# Application of Remote Sensing to the Chesapeake Bay Region

Volume 2 - Proceedings

## *Editors*

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A conference jointly sponsored by the National Aeronautics and Space Administration, Washington, D.C., the Environmental Protection Agency, Washington, D.C., and the University of Maryland, College Park, Maryland, and held at Coolfont Conference Center, April 12-15, 1977



National Aeronautics  
and Space Administration

Scientific and Technical  
Information Office

1978

This document makes use of international metric units according to the Systeme International d'Unites (SI). In certain cases, utility requires the retention of other systems of units in addition to the SI units. The conventional units stated in parentheses following the computed SI equivalents are the basis of the measurements and calculations reported.

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## PREFACE

The Conference on the Application of Remote Sensing to the Chesapeake Bay Region was sponsored by the National Aeronautics and Space Administration, the University of Maryland, and the Environmental Protection Agency. It was held at the Coolfont Conference Center, Berkeley Springs, West Virginia, April 12-15, 1977. This volume contains copies of the papers, resource contributions, panel discussions, and reports of the working groups. Volume 1 will contain a summary of the recommendations and conclusions of the conference.

The editors thank the other University of Maryland members, Patricia Maher (Inland Environmental Laboratory), and Anne Schmidt, for their invaluable aid in coordinating and carrying out the many facets of work involved in undertaking this Conference and in preparing these proceedings. The editors are also indebted to the Steering Committee members who reviewed material, offered advice, and provided invaluable Conference assistance.

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## INTRODUCTION

"The Chesapeake Bay, our nation's largest estuary, could, within our lifetime, become a dead sea. There is no time left to grope for solutions. With every year that passes, the Bay is diminished. Some day, unless we intercede, the wear and tear will become terminal. We must join together to ensure the health of the Chesapeake Bay as our legacy to the future."

Hon. Charles McC. Mathias, Jr.  
United States Senator—Maryland

This call for urgent, compassionate, and cooperative effort sounded the keynote of the Conference. The Bay region faces many and diversified problems. It struggles daily to survive man-made and natural impacts—nutrient loading and eutrophication, chemical and industrial pollution, thermal discharging, coastal erosion and silting, and a host of other maladies.

The federal government, state governments, and private organizations have established programs to address these problems. But too often the opportunities for the administrative and technical experts from these programs to interact and share information and new technological tools do not arise or are infrequent.

Remote sensing technology is a relatively new tool being used by a growing number of resource managers for monitoring and gathering information on the status of the Bay's health. Numerous research and applications projects have shown that Landsat and aircraft remote sensing technologies have important applications in land-use planning, water-quality and eutrophication monitoring, and a variety of other environmental conditions. Acceptance of the technology, however, has been slow. Again, the problem continues to be a lack of understanding and opportunities for communications between the groups that develop remote sensing techniques and those that require such techniques for solving environmental problems and for making policy decisions.

Thus, the Conference was planned and structured to encourage new working relationships and communication links between the organizations and individuals involved with managing the Bay. It was for these reasons that individuals invited to participate in the Conference represented federal, state, and private organizations and programs. The goals of the Conference were:

- To encourage future cooperative efforts amongst the Conference participants
- To focus attention on the value of remote sensing techniques in solving Bay problems associated with land-use, resources management, and pollution

- To identify and suggest new ways for improving services, research, and education in the field of remote sensing

The Proceedings contains papers prepared by the speakers and other conferees but not delivered. These provided material for discussion and working groups. Transcripts of the dialogue following two of the structured sessions; reports from the working groups; and a final address are also included. In addition, a paper describing the multicomunications structure of the Conference appears in Appendix A, and a list of the participants is contained at the end of the document.

Conference Coordinators:




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**SESSION 1**  
**OPENING SESSION**

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## INTRODUCTION

**Dixie A. Pemberton**

*Inland Environmental Laboratory*

*University of Maryland*

*College Park, Maryland*

Session 1 was planned to set the tone for the overall Conference. Speakers were needed who could effectively survey salient problems of land use, pollution, and resources in the Chesapeake Bay region on which remote sensing operations might best focus. Balance in presentations was provided by selecting three speakers with different perspectives: a public policy decision-maker, Maryland's U.S. Senator Charles McC. Mathias, Jr.; a technical program manager, Leonard Mangiaracina, Director of the Chesapeake Bay Program, Region III, U.S. Environmental Protection Agency; and an environmental educator and artist, Tom Wisner, agent of the Chesapeake Biological Laboratory. Because of technical difficulties, Mr. Wisner's program of original Bay songs and prize-winning slides are not contained here, but copies of his drawings are included in Appendix B.

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## THE CHESAPEAKE BAY: OUR REGIONAL RESOURCE

Hon. Charles McC. Mathias, Jr.  
*United States Senate*  
*Washington, D.C.*

It is a form of madness when someone like me presumes to talk to experts about the very area of their expertise. In my case, the madness is love-induced. My sole credential for discussing the Chesapeake Bay with the likes of you is that, for as long as I can remember, that Queen of Estuaries has been the object of my deepest affections. Therefore, I ask that you judge me with the tolerance reserved for lovers and not as you would each other.

I feel very much like the little girl, rummaging frantically through her closet early Sunday morning, who was overheard asking herself: "What can I wear today that Jesus hasn't seen?" I'm asking myself: "What can I say that you don't already know?"

For instance, I wonder if you know that, when I was young, oysters the size of a horse's hoof were commonplace at the very mouth of the Susquehanna River? Or, going back further, did you know that there once were sturgeon in our waters? Captain Gabriel Archer, who explored the James River in June 1607 with Christopher Newport, provides this catalogue of early marine life:

"The mayne River abounds with sturgeon very large and excellent good: having also at the mouth of every brook and in every creek . . . exceeding good fish of divers kindes, and in ye large soundes neere the sea are multitudes of fish, bankes of oysters, and many great crabbs rather better in tast than ours, one able to suffice four men . . ."

It's been a long time since we've seen crabs "able to suffice four men" on the Chesapeake. Today, the James River is better known for Kepone than for sturgeon. And those flats near the mouth of the Susquehanna that once boasted oysters the size of a horse's hoof are now dirty and barren.

Consider this: the oyster crop in 1880 comprised 56 million kg (123 million pounds) of meat; by 1968, according to a National Marine Fisheries survey, it had dropped to 11 million kg (25 million pounds).

These changes are the crux of our problem. At the rate things are going, the Chesapeake Bay—this nation's largest, richest estuary—could become a dead sea within our lifetime.

Although I am far from an expert on remote sensing, I do know enough about the results produced so far to forecast with confidence that this new technology can play a crucial role

in helping us save the Bay. Landsat's enormous potential is still largely untapped. It must be fully explored—then fully exploited.

I welcome this conference as a major step in that direction. I am proud to have first suggested such a symposium in the summer of 1974, and I wish you great success.

It is appropriate, I think, that the space-age technology of remote sensing be brought to bear on the Bay's problems because some of these problems were created by other forms of space-age technology.

Already, billions of tons of heated water are pouring into the Bay, and our growing appetite for energy brings new menace. Today's power plants are larger, often by a hundred times, than the plants that used to be built on free-flowing rivers. They consume more water than any river can provide, and utility companies look greedily at estuaries. At the present rate of energy consumption, the Middle Atlantic States will soon need at least 30 new nuclear plants on the Chesapeake Bay.

But, there is little reason to hope that consumption can be held at past levels. Escalating energy demands, combined with oil and natural gas shortages, could tax the Chesapeake Bay to death.

There are also other problems. In January, the Bay Grasses Oversight Committee asked Governor Mandel to fund a study to determine "unequivocally the effect of present and future pesticides on Bay grasses." This much is already known: the level of grasses in 1976 was half of what it had been in 1970 and nowhere near the 1960 level.

Recently, Maryland has had a shortage of crabs. Many believe the crab population is declining because of the destruction of the Bay grasses, where shedding crabs once found safe haven from predators.

Everywhere in the Norfolk-Washington-Baltimore corridor growing industrial, commercial, recreational, and urban activity threatens the environmental quality we have loved so much, but understood so little.

The Bay endures, fighting each new threat with its own prodigious regenerative powers. But the danger signs multiply:

- Kepone has shown up in bluefish and rockfish in the Bay.
- Poorly treated sewage is flushed in increasing amounts into Bay waters.
- Wetlands are disappearing.
- Deadly chemicals are discharged daily into Bay waters.



- During 1976, there were two major spills of dangerous liquids, and, considering Bay traffic, it is amazing there weren't more. Traversing the Bay annually are: 476,800 commercial vessel trips, 125 Navy ships, 81 Coast Guard ships, 14,350 fishing boats, 110,750 licensed pleasure craft, and an untold number of other pleasure boats.
- The upper Bay is losing salinity.

These are just a few of the ways in which man abuses the Bay. Year-by-year, they take their toll. The Bay is finite and, although the effect is not terminal, it is plainly measurable. The watermen see it daily, and they express their outrage: "We have to make a living out there and half the stuff we pull out is dead," said one Calvert County waterman. Another spoke freely of the impact chemical pollution has on even the smallest water creature: "We're all related to that creature. When we destroy him, we destroy part of ourselves. . . ." Other watermen have told me of catching fish full of worms.

We are only beginning to see the effect of our tampering with the Bay's ecostructure. But the Bay is still surprisingly healthy, considering the punishment it has taken. Most wetlands are unfilled. Fisheries have been reduced but not wiped out. Wildlife in all its forms, from the Canada goose to the tiniest organism in Bay shallows, flourishes stubbornly. The beauty and grandeur of the Chesapeake remain.

Recent events even hold out some encouragement. Maryland has enacted tough laws to ensure clean air and water and to protect wetlands and wildlife. Hundreds of environmental cases are brought to court each year. Local governments have slowed development with zoning laws. National air and water-quality laws were strengthened in 1970 and again in 1972.

Not only has the regulatory framework been shored up by new laws and by the dedication of those who administer these laws, but Maryland's research facilities have improved tremendously. This is something you know far more about than I do, and it's something to be proud of.

Another very significant development is the growing citizen concern about the future of the Bay. Last month, I spoke at the Annual Meeting of the Chesapeake Environmental Protection Association (CEPA). This group has been fighting increases in the temperature of the water effluent at Calvert Cliffs.

Its effectiveness was recognized in a recent wrap-up story in the *Washington Post* about area utility companies putting the brakes, at least temporarily, on nuclear power plant construction. The *Post* reporter wrote:

"All parties agree that CEPA's years-long tenaciousness has been at least partially responsible for changes in state and national government standards and regulations for nuclear power plants and even landmark court rulings requiring that environmental considerations be part of the official licensing process."

That is a pretty powerful accomplishment, and it points to the enormous contribution that such citizens' groups are making and can make to the preservation of the Bay.

One of the things I talked about at that meeting was Landsat because I think it's important that each group working to preserve the Bay know the strengths and capabilities of other groups. Thanks to NASA, I was able to show the dramatic Landsat pictures of ice conditions on the Bay this winter. With reports about the ice's destruction of Bay life still fresh in everyone's mind, they made a pretty impressive demonstration of Landsat's unique potential.

There have been some accomplishments at the Federal level, too. After Congress passed my proposal for a study of the Bay, Russell Train, then Administrator of the Environmental Protection Agency (EPA), acted on this Congressional mandate. Last May, he announced a 3- to 5-year program, with an annual budget of 5 million dollars, devoted to studying and preserving the Chesapeake Bay.

This victory for the good guys has been dimmed somewhat by the failure of the Office of Management and Budget (OMB) to authorize to EPA the additional positions required for the Chesapeake Bay Study. OMB apparently has told EPA to reprogram 10 positions for this project instead of providing it with additional positions as specified in the legislation. Although I have protested OMB's action, or rather lack of action, the matter has not yet been resolved.

On the more positive side, there is the spirited and imaginative work being carried on by the Chesapeake Bay Center for Environmental Studies of the Smithsonian Institution. The Center, as many of you know, occupies some 10.5 million km<sup>2</sup> (2600 acres) on the Rhode River, a subestuary on the western shore, 16 km (10 miles) south of Annapolis. It grew around the site of an old dairy farm bequeathed to the Smithsonian by the late Robert Lee Forest. Smithsonian Secretary S. Dillon Ripley accepted the bequest and organized a series of land acquisitions, funded by private foundations, until the Center covered a showcase estuarine/watershed ecosystem.

It began work in 1971 with a study of the Rhode River and its watershed. The Rhode River Program was jointly funded by the Smithsonian Institution, Johns Hopkins University, and the University of Maryland. Marshland, nutrient cycles, land runoff, and water fowl were all studied: the full panoply of Bay ecology. The research has already provided crucial insights. It determined that the bacteria that have poisoned Rhode River shellfish came almost entirely from land runoff. It discovered that Rhode River nitrogen nutrients are brought by the rain. And it suggested that marshes are more vital spawning and nursery grounds than had been supposed. This is the kind of research that will yield the insights we must have to save the Bay.

Because of the nature of the Smithsonian operation, the Chesapeake Bay Center for Environmental Studies could become the cornerstone of a national movement to save the Bay. It has already stimulated wide appreciation, as well as scientific interest, in this precious natural resource. I hope that, as we move forward in our campaign to save the Chesapeake, the Smithsonian will throw its weight behind us nationwide.

Obviously, many fine people are doing many fine things about the Bay. Why, then, do we seem to be taking two steps backward for each step forward? The single great flaw in our array of programs, laws, research projects, citizens' lobbies, and space-age technology is that federal, state, local, and private agencies have no workable way to coordinate their stewardship of the Bay.

The Bay is an organic whole. If one part is damaged, all parts are affected. It is of little use to study one link in an environmental chain without relating it to the whole. The conclusion is obvious: If the Chesapeake Bay is to survive, it must be addressed as an entity—as a total system—without duplication and without omission.

In the summer of 1973, I made a 5-day inspection tour of the Maryland shore and subestuaries of the Bay. In my report on that trip, I proposed a method for coordinating and unifying the massive conservation effort that the Chesapeake so badly needs. I have revived that proposal regularly ever since, and I am about to revive it again here tonight.

But first, let me read you a short passage from Swepson Earle's *The Chesapeake Bay Country*, published in 1923. He writes specifically of oystering and of the Bay in general:

"Maryland has established no really constructive policy to maintain this great natural wealth . . . . The State of Virginia through oyster culture and planting on a large scale, has been able within the past decade to stem depletion within its waters. The citizens of Maryland, if they propose to maintain this great natural resource, must get together on a broad and constructive plan, or it will be only a matter of years before the watermen with their picturesque craft will be forced to find other means of livelihood, while the state's loss will be many millions of dollars."

Today the Horn Point Branch of the University of Maryland's Center for Environmental and Estuarine Studies is now doing something about the oyster depletion in Maryland. They are trying to develop a production-size oyster hatchery in which scientists will be able to spawn and grow oysters to plant on oyster bars around the Bay. Drawing on findings from the University's Chesapeake Biological Laboratory at Solomons Island, which has been in the oyster business for years, the hatchery at Horn Point hopes to be able to replace one-tenth of the Bay's natural harvest. This year, when we must expect a much smaller harvest than usual, this is no small thing.

So, we are at last beginning to do something about oyster culture over half-a-century after Swepson Earle first mentioned the problem. Perhaps it is time to consider his other suggestion as well: that "the citizens of Maryland get together on a broad and constructive plan . . . ." to maintain this great natural resource.

All of which brings us back again to my proposal. It is simply this: that a commission be set up to oversee and coordinate conservation of the Bay. The procedure would be simple. The Water Resources Planning Act of 1965 contains, in Title II, authority to fund such commissions at up to \$750,000 a year. There are seven Title II commissions across the country today. Membership is drawn from state and federal agencies, with a chairman appointed by the President of the United States.

Such a commission would join Maryland and Virginia in a partnership. The two states, as well as state and federal governments, must combine in managing the Bay. Most of the fresh water for the Chesapeake runs in from Maryland rivers; saltwater flows off the Virginia Capes. The two states are common sharers, common contributors, and common stewards; they have an equal interest and an equal responsibility.

But they would act on behalf of the country as a whole. The Chesapeake—our largest and most fertile estuary—is a natural resource of national dimension. One look at any Landsat picture of America will confirm this. The Chesapeake stands out boldly on our national landscape.

I believe that a Title II Commission that would coordinate and integrate all our interests could preserve the Bay. I am fighting for it. I ask you to join me.

There is no time left to grope for solutions. With every year that passes, the Chesapeake Bay is diminished. Unless we can get together and intercede, some day the wear and tear will prove too much.

There is no way to turn back the clock. We cannot return to those simpler times when my romance with the Bay began. We cannot banish our technology or its effects. But we can tame it. We can restrain its deadly abuses. And we must. The Chesapeake Bay is our legacy—more precious to us than anything man has made. Today, we hold its life in our hands.

## THE CHESAPEAKE BAY PROGRAM: AN OPPORTUNITY TO USE AN INNOVATIVE MONITORING TECHNIQUE

Leonard Mangiaracina  
*Environmental Protection Agency  
Philadelphia, Pennsylvania*

### INTRODUCTION

Congress has directed the Environmental Protection Agency (EPA) to conduct an indepth study of the Chesapeake Bay, with potential applicability to other estuarine zones. On the basis of guidance contained in the Senate Committee Report on the 1976 Appropriation Bill for EPA, the Chesapeake Bay Program has been established under the responsibility of the Philadelphia Regional Office. The goal of this program is to develop a management system that will protect and preserve the water quality of the Chesapeake Bay by effectively managing its uses and resources. To achieve this goal, three major objectives must be accomplished:

- Determine what units of government have management responsibility for the environmental quality of the Chesapeake Bay. Define how such management responsibility can best be structured so that communications and coordination can be improved between the respective units of government, research, educational institutions, concerned groups, and individuals. In addition to examining the Chesapeake Bay management mechanisms and institutions, review new alternatives for improving these mechanisms if they appear promising.
- Assess the principal factors having an adverse impact on the environmental quality of the Chesapeake Bay. Following this assessment and review of ongoing research, direct and coordinate research and abatement programs that will most effectively address these factors.
- Analyze all environmental sampling data now being collected on the Chesapeake Bay and suggest and undertake methods for improving this data collection. Establish a continuing capability for collecting, storing, analyzing, and disseminating these data. When deficiencies are found in the present sampling programs, institute a sampling program.

### OBJECTIVE 1

Objective 1 of the program will be of a phased or modular nature. This approach will permit the Chesapeake Bay Program to modify and redirect the study as institutional/regulatory/management problems and issues become better defined. The first phase will be an institutional analysis focusing on water quality and related resource problems of the Bay—their relationship

to existing agencies, programs, laws, and regulations and the management issues they raise. Descriptive information on legal responsibilities, regulatory processes, decision-making processes, and institutional arrangements for specific existing problems of water quality will be developed. This will provide the basic identification of the existing institutional structure, the types of problems encountered, and the effectiveness of existing management tools, and will serve to identify deficiencies.

As the study progresses, the analyses will focus on the intergovernmental system as it relates to conflicting uses of the Chesapeake Bay. With an understanding of the "system" in relation to the use of the resources of the Chesapeake Bay, it should be possible to determine how new conflicts can be resolved. It should also be possible to demonstrate how changes in statutory authority or governmental management systems will affect specific uses. The capability to predict the consequences of modifying the management system is essential for identifying and evaluating alternatives to improve that system.

As alternatives are identified and evaluated, increasing interaction with new technical information generated by our program will permit the refinement of alternatives because a recommended management structure must relate substantially to specific technical/environmental problems being addressed.

## **OBJECTIVE 2**

The Appropriations Bill directs EPA to "... assess the principal factors having an adverse impact on the environmental quality of the Chesapeake Bay, as perceived by both scientists and users and to direct and coordinate, subsequent to a review of presently ongoing research, research and abatement programs that will most efficiently address those factors."

To determine what is perceived to be the principal factors that adversely affect the Chesapeake Bay, citizens, scientists, and government agencies will be canvassed. A valuable source of information that will be used to determine the concerns of the Bay community will be the forthcoming Bi-State Conference on the Chesapeake Bay.

To maintain a continuous dialogue with the users of the Bay, a Citizens Committee will be formed, and a strong public participation program will be developed. When the course of the research program has been determined, both past and ongoing research activities will be reviewed to determine what programs must be initiated to satisfy the identified needs of the Chesapeake Bay Program.

## **OBJECTIVE 3**

In the Appropriations Bill, Congress recognized the fact that an extensive amount of data have and are being collected on the Chesapeake Bay. Congress therefore directed EPA to "... analyze all environmental sampling data presently being collected on the Chesapeake Bay and to suggest and undertake methods for improving such data collection. The Agency



is also directed to establish a continuing capability for collecting, storing, analyzing and disseminating such data. A sampling program should be instituted where deficiencies are found to exist in present sampling programs."

To establish a capability as directed by Congress, the Chesapeake Bay Program will determine the data system needs of the Bay managers and the requirements of the scientific community. On the basis of the needs identified, the Chesapeake Bay Program will then determine the data-management system requirements. This data system will be designed to act as a management tool for government agencies and the Baywide data bank for the Chesapeake Bay community.

Existing data systems will be reviewed to determine if any of these systems, either in whole or in part, could be used to fulfill the identified needs. Subsequent to this review, a data system would be developed.

To determine what type of data are necessary for assisting management in making decisions regarding the water quality of the Chesapeake Bay and what data are necessary for providing information about the identified principal factors, the Chesapeake Bay Program will analyze all data now being collected. A data-collection program will then be initiated that will use relevant existing programs and that will begin new data-collection efforts in areas found to be deficient.

In the initial directive to the Environmental Protection Agency to carry out a Chesapeake Bay Program, EPA was directed to internally reprogram 5 million dollars to fund the program, and the Office of Management and Budget was directed to release 50 positions for program staffing.

The Office of Management and Budget did not release the 50 positions, and, because of budgetary restrictions, EPA was unable to reprogram 5 million dollars.

The regional office was then directed to develop program alternatives based on decreased resource levels. The region was allocated 10 positions and a budget of \$500,000 to initiate the planning phase of the program.

To operate the program in FY 1977, Congress had requested a budget of 5 million dollars and a resource level of 50 positions. At present, the Office of Management and Budget has approved a funding level of 5 million dollars, but has not authorized any positions for FY 1977. We are operating at a staff level of 10 positions.

For FY 1978, the program has received 10 positions from the Office of Management and Budget. Unfortunately, this does not amount to any net gain of positions, but simply "covers" the current positions allocated to the program by EPA. As you are aware, it is difficult to effectively administer a 5-million-dollar program with a limited staff. We are optimistic that a number of additional positions will be allocated to the program, but, at this time, we do not know the exact number.

Since the announcement of the Chesapeake Bay Program last May, the Agency has made progress in developing this program. During this period, the Chesapeake Bay Program has made its presence felt in the Bay Community. Although the program is essentially a planning program, it has become actively involved in some of the immediate problems of the Bay, such as the Kepone situation.

Preliminary studies indicate that potentially detrimental environmental factors affect the Bay's ecosystem. In our study of rooted aquatics, the presence of herbicides has been found. In our study of rock-fish eggs, concentrations of polychlorinated biphenyls have been found. Although neither of these findings are any cause for alarm, they do represent trend indicators. The environmental factors that have been surfaced, the concerns of the citizens, the academic community, and the states, will form the basis for the indepth technical programs that the Chesapeake Bay Program will sponsor.

The Chesapeake Bay Program will continue to coordinate with ongoing programs that are being undertaken by other federal and state agencies. Interagency agreements have been executed between EPA and the Department of Interior's Fish and Wildlife Service, the Corps of Engineers, and the National Science Foundation. Contracts have been given to the State of Maryland, the Virginia Institute of Marine Science, the Smithsonian Institution, and the Chesapeake Research Consortium. A wealth of expertise exists, and the Chesapeake Bay Program intends to utilize the existing experience whenever possible. With the states of Maryland and Virginia and the Baltimore Corps of Engineers, the Chesapeake Bay Program will co-sponsor the Second Bi-state Conference on the Chesapeake Bay. Coordinated by the Chesapeake Research Consortium, the conference will be a valuable source of information for the program and will provide additional material that will assist EPA in determining the direction of the technical programs. The program will be implemented in a manner that will complement and reinforce other ongoing Baywide pollution-abatement efforts at the federal, state, and local level. During this initial period, we have established coordination mechanisms both within EPA in related program areas and externally with federal, state, and local agencies. We believe that programs for protecting the environment are most effective when a cooperative spirit exists. Hopefully, these coordination efforts will lead to a comprehensive program where resource utilization will be maximized.

The major pollution problems of the Chesapeake Bay originate from point and nonpoint sources. The National Pollution Discharge Elimination System permit program under Section 402 will be used to determine what point-source discharges are entering the Chesapeake Bay basin. A preliminary inventory of 402 major discharges has been completed. Priority has been placed on tracking the compliance/noncompliance status of these dischargers, as well as of the toxic substances reported in the permit.

The program staff has also been working with the EPA project officers of the designated 208 areas in the Chesapeake Bay basin to use their plans, when possible, as an integral part of the Chesapeake Bay water-quality management system. The 208 nonpoint source program,



as well as the Coastal Zone Management Program, may be used to identify control measures from nonpoint waste loads. Information from these programs will provide the major thrust toward accomplishing Objective 3, the data collection and data management portion of the program. It is in this last program objective that we find the potential opportunity to use remote sensing techniques in the Chesapeake Bay Program.

The Chesapeake Bay is 311 km (193 mi) long and is divided between two states. Three other states contain tributaries of the Bay that can affect its quality. The Bay's great size and the jurisdictions that have control over it make comprehensive monitoring programs difficult. Remote sensing techniques can help to transcend these difficulties and permit us to view the Bay as a unified system.

Remote sensing may be of particular help with nonpoint source pollution. Runoff from urban and agricultural areas is considered to be a major factor relating to the water-quality conditions of the Bay. However, nonpoint source pollution is both difficult to monitor and to analyze. The greater range of area covered by remote sensing techniques could help to determine the extent and location of the Bay's nonpoint source related problems.

We hope this workshop will help to familiarize all of us with the capabilities and the potentials of remote sensing and allow EPA to better assess its potential use in meeting the objectives of the Chesapeake Bay Program.



**SESSION 2**

**ROLE OF REMOTE SENSING IN LAND-USE  
PLANNING IN THE CHESAPEAKE BAY  
WATERSHED**

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## INTRODUCTION

**Robert M. Ragan and Dixie A. Pemberton**

*University of Maryland*

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The planning and management of the land and water resources of the Chesapeake Bay system must reconcile a complex array of conflicting demands. Thus, decision-makers working in this field must use every aid available to them as they anticipate the consequences of their actions. A very important phase of this decision-making process involves the determination of the land-use distributions surrounding the Chesapeake Bay and its tributary watersheds. Without this land-use information, a thorough understanding of the Chesapeake Bay system is not possible.

Models developed for simulating population dynamics, water quality, economics, or hydrology have become important tools to the decision-maker. The most flexible models require land-use distributions as one of the primary inputs. For example, a number of land-use based hydrologic models have been developed for simulating the behavior of the stream flows or water-quality parameters in terms of land cover. The advantage of such a model to the decision-maker is that the model can be calibrated to reflect the present hydrologic or water-quality consequences of the existing land-cover pattern. Once the decision-maker is satisfied that the model adequately represents his system, he then has a tool that permits him to experiment and to evaluate the impact of changes that he may consider. In this context, he can also use the model to locate areas that may be disproportionately impacting a particular problem. Unfortunately, estimating model parameters in terms of land cover is a very difficult and time-consuming task when areas larger than several square kilometers are involved. Parameters estimating problems frequently lead decision-makers to adopt simpler models that require less detailed input data or to inadequately define the data required by the model. Without remote sensing, definition of land cover in an area as vast as the Chesapeake Bay region would be next to impossible.

Session 2, Role of Remote Sensing in Land-Use Planning in the Chesapeake Bay Watershed, presents several papers and discussions dealing with problems of using remote sensing technology in the Chesapeake Bay area. Dr. Cressy explains that the evolution of a system proceeds through three steps: a research and development phase, a transitional phase, and an operational phase. Dr. Cressy concludes that the use of remote sensing is now in the transition phase. Actually, the phases cannot be totally isolated. To the frustration of a number of potential users, considerable research and development continues well into this

transition phase. Thus, when a decision-maker thinks of remote sensing, he becomes concerned that so much research and development is continuing to be emphasized. On the positive side, there are cases in which remote sensing has actually become operational even though we are still in the traditional phase in so many other areas. As an example of technology in the operational phase, James Manley of the Regional Planning Council in Baltimore, Maryland, presents a paper that discusses the use of satellite remote sensing as part of their "208 Study."

C. E. James of the Environmental Protection Agency explains that the size of the Chesapeake Bay watershed will require years, or perhaps decades, of surveillance and analysis to adequately assess the hydrological, climatic, and biological cycles involved. As with so many tools, C. E. James concludes that the scientific, engineering, and technological expertise of remote sensing exists for the development of a coherent program. However, the mechanics of coordination, communication, and administration will require continuing work. Robert W. Douglass of the Forest Service recognizes this type of gap between technology and organizational problems when he explains that a change in technology level must also dictate the change in the level of decision-making. A major problem in the Bay watershed will be the management of remote sensing data because of the size of the Bay. John Antenucci of the Maryland Department of State Planning, who replaced Edwin L. Thomas, explained the Maryland Automated Geographic Information (MAGI) System. The MAGI system is a state-wide geographical data base in which variables needed for broad-scale planning are stored in cells representing  $0.36 \text{ km}^2$  (90-acres) each. James Wray and James Manley also discuss the problems of data management that will be so important to the successful application of remote sensing in the bay region. Kenneth N. Weaver of the Maryland Geological Survey presents a paper that illustrates the importance of being able to interface data from numerous sources in any data-management system. Dr. Weaver explains that satellite and other remote sensing methodologies have an important application in the Bay. At the same time, some of the older techniques, such as seismic-reflection profiling for geophysical exploration, must be interfaced if the decision-makers are to have all of the needed information available to them.

Following the series of papers is a transcript of a panel discussion that was held immediately after the small-group work sessions. The discussion was directed toward answers to a series of questions that were presented in writing from the working groups of conferees. Although these questions were not taken in a specific order, most of those relevant to the mission of the panel were discussed. Those that were not discussed are listed at the end of the panel discussion, along with the names of people who are willing to respond to these or similar queries. If you wish to communicate with them, their addresses and telephone numbers appear at the end of this document.

## PRESENT STATUS OF LANDSAT REMOTE SENSING

Phillip J. Cressy  
*Goddard Space Flight Center  
Greenbelt, Maryland*

The purpose of this presentation is to examine the state-of-the-practice of satellite remote sensing. The emphasis will not be on the status of Landsat technology itself—others at this conference will be thorough in this regard—but rather on the use of remote sensing to improve information gathering practices. Impediments to adopting this technology and opportunities to overcome these impediments will be addressed.

The present Landsats (-1 and -2) are the most recent and sophisticated in a series of remote sensing experiments that date back to Gemini and Apollo orbital photography. Considerable research has been conducted to translate the data collected under all of the National Aeronautics and Space Administration's (NASA's) experimental programs into usable information forms, as the literature of this technology in the last 15 years attests. Although some organizations have successfully integrated Landsat data into operational procedures, such successes do not compare with use of, for example, communications and meteorological satellites.

In the "Report to the National Research Council on Practical Applications of Space Systems" (1974 Summer Study), the Panel on Institutional Arrangements identified three distinct steps in the evolution of space systems: a research and development (R&D) phase, a transition phase, and an operational phase. Research and development must continue to support the growth of any technology, but remote sensing of Earth resources has evolved out of a basically R&D activity into a transition phase, with some instances of operational acceptance.

What are the characteristics of the transition phase? For one thing, one should note a shift in emphasis from technology development to application. NASA has made a considerable investment in remote sensing technology development, largely through universities and government and private research institutions. Although some of this type of support must be maintained, a noticeable shift to applications is now underway. The Landsat-1 Principal Investigator Program concentrated on determining what information could be extracted from Landsat data. The Landsat-2 Program required the involvement of operational organizations, thus emphasizing the practical aspects of such information. Other federal agencies—Corps of Engineers, Environmental Protection Agency, and Departments of Interior, Agriculture, and Commerce, to name just a few—are also beginning to examine the practical uses of remote sensing technology for their program needs.

This focus on practical applications brings with it new responsibilities. Technologists have a tendency to concentrate on technologically interesting problems. The technologist must

resist the urge to take his solution and go looking for the right problem. He must instead develop working relationships with the user to better understand the user's information needs and to help the user come to grips with a new technology.

The potential users of remote sensing must also work at these relationships. They must be patient with the awkward efforts of scientists who are unfamiliar with their worlds and must not be deterred by technologists who become part of their problem, if only temporarily, rather than its solution. The users must be prepared to look beneath the sometimes "glib" magic of remote sensing technology and to deal with this technology as they have dealt with other technical innovations on their own practical level.

Another aspect of the transition phase is the degree to which the potential user has access to remote sensing technology. Here "technology" means both the data and the ability to extract information from these data. The data handling process, from NASA through the U.S. Geological Survey's Earth Resources Observation System (EROS) Data Center to the public, was never intended to support operational requirements for turnaround time. The frequency of satellite overpass is inadequate for monitoring some dynamic phenomena. But perhaps the most important aspect of data availability impeding progress toward operational use is the lack of a long-term commitment to an operational Earth observation program. It is a classic chicken-and-egg problem. Governmental agencies and private industry are reluctant to become dependent on satellite data as an information source—to make a large investment in this technology—until they are assured that these data will continue to be available. Yet, just such a dependency seems to be needed to substantiate a large federal investment in an operational Earth observation satellite system.

A similar situation exists between users and private industry. The service and equipment industries have been developed in support of the R&D effort. Thus, at least two recent examinations of the opportunities for low cost digital processing systems were unable to find systems that cost less than \$100,000—not a frightening figure to some R&D institutions, perhaps, but probably out of reach of, for example, a regional planning commission or state geological survey. As S. S. Viglione (McDonnell-Douglas) put it, "the business community is faced with the problem of attempting to provide an ill-defined product to an uninformed consumer to satisfy some real and some yet to be determined needs and requirements." Some vendors claim that the user market is not aggregated. The vendor industry, with a market in the research and development world, is not prepared to take significant institutional risks to address such a scattered and relatively impoverished market.

Therefore, the status of remote sensing today is clearly transitional. Assuming this new technology warrants such development, how do we move toward an operational phase? We—technologists and managers—must concentrate our efforts on the institutional mechanisms by which remote sensing technology can be adapted and adopted for operational use. Success in applications must be measured in terms of processes that satisfy user information needs, that are consistent with user resources, and that offer the least disruption to the institutional environment in which these resources are to be applied.



Recent NASA initiatives are aimed at addressing these issues in regional facilities at Ames Research Center (California), Earth Resources Laboratory (Louisiana), and, particularly appropriate to the Chesapeake Bay Region, Goddard's Information Transfer Laboratory (Intralab). In a variety of settings, potential users are being given the opportunity, working with remote sensing experts, to test the application of remote sensing technology against their information needs. The purpose of these programs is to enable potential users to discover for themselves the value of remote sensing and the processes by which they can use such data routinely. The programs are successful to the extent that customers' experiences lead them to become independent users of the technology. Remote sensing will make great progress toward operational status as these "adopters" themselves become "change agents," influencing and assisting other potential users to integrate remote sensing technology into their operations.

Forums such as this workshop are needed as a mechanism to review where our applications efforts are today and where they might well be tested in the future. The interactions of technologists, potential users, and change agents provide the opportunity to match technology with issues and to explore options for the transfer of remote sensing applications to operational use.

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## ACTIVITIES OF THE U.S. GEOLOGICAL SURVEY IN APPLICATIONS OF REMOTE SENSING IN THE CHESAPEAKE BAY REGION

**James R. Wray**  
*U.S. Geological Survey*  
*Reston, Virginia*

The application of remote sensing in the Chesapeake Bay region has been a central concern of three project activities of the U.S. Geological Survey (USGS): two are developmental, and one is operational.

Jointly sponsored by the National Aeronautics and Space Administration (NASA) and the Department of the Interior Earth Resources Observation System (EROS) Program, the two developmental activities were experiments in land-use and land-cover inventory and change detection using remotely sensed data from aircraft and from the Landsat and Skylab satellites. One of these is CARETS (Central Atlantic Regional Ecological Test Site), headed by Robert H. Alexander. The other developmental task is the Census Cities Experiment in Urban Change Detection headed by James R. Wray. Elements of such research continue under full USGS auspices to serve specific agency objectives.

The present major concern is an operational land-use and land-cover data-analysis program, including a supporting geographical information system. It depends heavily on remotely sensed data, but also on much that is not. Now in its third year, this program is nationwide in scope and will therefore provide coverage of the Chesapeake Bay region. With the participation of cooperating state agencies, it will take another 5 years to complete first-time national coverage. Update of selected areas mapped earlier is expected to begin in 1979.

For this (April 1977) remote sensing conference for representatives of Chesapeake Bay region agencies, the USGS has provided materials that describe features of the national land-use and land-cover data-analysis program. We are also providing a full description of reports and maps resulting to date from the CARETS and Census Cities research projects. Informal exhibits, and knowledgeable geographers to discuss them, are also available.

The main thrust of the formal workshop presentation is a comparison of experimental techniques and products, primarily for the Washington, D.C., urban area. These include some promising recent developments in machine interpretation of multispectral digital data from Landsat. An integrated sequence of five steps in a semiautomated regional information system is illustrated:

- Initial land-cover inventory
- Intermediate map-like product generation

- Area analysis by jurisdictional statistical areas
- Preparation of separation plates for publishing a thematic land-cover map
- Detection of land-cover change and update

Products and applications (and related user experiences) from demonstrations in the San Francisco Bay and Puget Sound regions are also offered. These provide perspectives on:

- The problems and requirements of user agencies in the Chesapeake Bay region
- To what extent evolving tools and techniques promise help

In study group sessions during this Conference, USGS personnel provided additional information on details of activities, products, and user applications.

## OPERATIONAL PROGRAMS IN FOREST MANAGEMENT AND PRIORITY IN THE UTILIZATION OF REMOTE SENSING

**Robert W. Douglass**

*Forest Service, U.S. Department of Agriculture  
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The Forest Service of the U.S. Department of Agriculture has the Federal responsibility for national leadership in forestry, including participation in setting national priorities, formulating programs, and establishing Federal policies that relate to man and his natural environment. In addition to managing the lands in the National Forest System, which comprise an area larger than France, Switzerland, and Belgium combined, the Forest Service performs research at 80 stations throughout the United States and assists state governments and private industry in managing 2554 million km<sup>2</sup> (631 million acres) of nonfederal forest and rangeland.

Two recent pieces of legislation, the Forest and Range Resources Planning Act of 1974 and the National Forest Practices Act of 1976, provided an expanded mission for the Forest Service. Under the Resources Planning Act and its amendment, the Forest Service is charged with producing an assessment of all forest and rangeland resources on a 10-year interval.

The magnitude of the problem faced by the Forest Service in assessing renewable resources for 6.5 billion km<sup>2</sup> (1.6 billion acres) of land, for making management decisions, or for giving technical assistance dictates some application of remote sensing.

The planning processes that Forest Service personnel follow requires a great deal of information about the resources. Therefore, the data base that serves in the decision-making process must be as complete as possible. This means more than just collecting inventory data. Data processing, manipulating, and storage, along with end product and display capability, are more important right now than an increase in the data collection.

Since I was asked to talk about operational remote sensing programs in forest management and the priority in the use of remote sensing, I shall discuss the general application in forestry, not just the Chesapeake Region, and I shall concentrate on Forest Service priorities in using remote sensing.

I recognize remote sensing as the collection of data about a scene from a distant place—generally considered to be airborne or orbital platforms—using cameras, microwave, or multi-spectral scanner systems and the interpretation of these data by manual or machine processes. Aerial photography, its use, and its applications are considered to be part of remote sensing.

All of the operational uses of remote sensing in forestry presently employ aerial photography. None are dependent on Landsat data. Although aerial-photograph interpretation has been

used in forestry since 1927 and is widely accepted as an operational tool, it is still not fully utilized in some cases. It should be understandable that an experimental system such as Landsat is not considered to be operational to forest-land managers when no reliable, regular use can be made of the data that Landsat now provides. Data characteristics, Landsat philosophy, and foresters' way of doing business have dictated that Landsat-1 and -2 are not operational systems.

The U.S. Department of Agriculture has completed a study of remote sensing user requirements. The initial findings indicate that approximately 1200 user requirements can be met by remote sensing. However, Landsat-1, -2, or -C, with its 80-meter resolution, can satisfy 8 percent of the requirements, and Landsat follow-ons theoretically should satisfy 12 percent more requirements. It is not surprising to note that almost one-half of the user requirements identified in this study can be met with 1-meter resolution in a camera system.

In forestry, the increased quality of film emulsions and camera systems have led to some changes in the use of photointerpretation. True color negative and color infrared transparencies are becoming routine resource photography. More significant than the increased use of true color and color infrared is the application of small-scale photography in place of large-scale imagery. As previously stated, air photointerpretation has been part of forestry since the 1920's. After World War II, most of the professional forestry programs in the major universities offered forest photointerpretation or photogrammetry courses. Today, many universities have combined computer technology with image interpretation to provide remote sensing courses.

Remote sensing has become such an integrated tool in forestry that there is difficulty in splitting its costs and benefits. My most recent estimates of Forest Service remote sensing expenditures were 1.7 million dollars in FY 1976, climbing to more than 2.1 million dollars by FY 1978. These figures do not include all of the money spent by the National Aeronautics and Space Administration (NASA) in the Forestry and Range Applications Development Programs.

What does the Forest Service get for this kind of dollar expenditure? It gets a major contribution to its data base from photogrammetry and photointerpretation. Routinely, we require multiple resource photography at an approximate scale of 1:24,000 and mapping photography at a scale of 1:80,000. Although true color and black and white dominate the choice of film types, color infrared and infrared black and white films are also used.

A scheduling routine has put acquisition of new resource and mapping photography on an approximate 5-year schedule. All resource and mapping photography is flown at Agriculture Stabilization and Conservation Service specifications. Our cartographic workshop in Salt Lake City is responsible for producing base maps of 1:24,000 and 1:31,680 scales from the quadrangle centered 1:80,000-scale black and white photography. The 1:80,000 scale is used because one frame covers one 7.5-minute quadrangle sheet. Various special-mission photography is flown as required for research or for special purposes such as fire appraisal or insect infestation appraisals.

In addition to the operational use of air photos for resource management and for mapping purposes, the Forest Service uses remote sensing technology in several ways to work out special problems. The Southeastern Region in Atlanta is now evaluating a Soil Resources Inventory System based on stepwise interpretation of 1:60,000 color infrared photography supplied by NASA that was developed at the Johnson Space Center. After this system of performing the Soils Resource Inventory is transferred to the Forest Service, it is expected to be used in areas of the National Forest System such as the wilderness areas where sufficient time or funds are not available to perform a detailed soil survey.

Nonphotographic forms of remote sensing are used operationally. Perhaps the most famous application is the Fire Scan Project that employs an aircraft-mounted thermal scanner to map the location of fire through the forest-fire smoke. The Forest Service developed the thermal detection and mapping system as a front-line aid to the fire boss. An offshoot of the aircraft detection system has been the tower-mounted radiometers to supplement manned fire towers.

Although Landsat data are not collected in picture form, the digital data can be exhibited in a picture format, thereby making it available for manual interpretation.

For one forest, the Tahoe National Forest, the soil scientist has incorporated manual interpretation of Landsat imagery into the Soils Resource Inventory to make the procedure more efficient.

The Forest Service has a cooperative Forestry Applications Program with NASA at the Johnson Space Center. The Forestry Applications Program (FAP) is responsible for developing remote sensing applications of satellite and other space platform data that will assist in accomplishing the Forest Service mission. It has been charged with developing the remote sensing methodology for:

- Large-area forest and rangeland inventory
- Insect and disease impacts on forests
- Monitoring environmental effects of management activities

FAP, the major large remote sensing developmental effort of the Forest Service, employs approximately 18 man-years of effort. Much of the NASA-funded forestry remote sensing research is in support of the Forestry Applications Program.

So far, I have said very little about forestry in the Chesapeake Bay Region or specific forestry applications of remote sensing there. My earlier comments about resource and mapping photography being an integral part of forestry planning and management holds true in this region. State, federal, and company foresters obtain much of their resource data by air photointerpretation. Aerial photographs will probably remain the primary source of establishing the required data base.

Presently, the U.S. Department of Agriculture has approximately 80,000 data-collection stations gathering data on a variety of subjects, such as snowpack depth, wind velocity, stream flow, and wilderness visitors. We are beginning to consider alternatives to the field readouts of these stations by utilizing satellite-oriented telemetry and relay. The Forest Service has purchased seven data-collection platforms (DCP's) for use in an Alaska state-wide water-resources study. The DCP's will be the Forest Service's first application of the satellite communications capability for collecting data in remote locations.

Although Landsat has been used for several studies concerning forest and range resources, it has not yet produced the accuracies needed to perform many operational tasks. Our studies at the Johnson Space Center indicate that the 40- to 80-percent levels of correct classification achieved with the 80-meter resolution of the present satellites should improve significantly with the 30-meter data from the Landsat follow-on in 1981. However, the remote sensing data-collection parameters will not increase the quality of data until then.

We have reached a plateau in the climb towards better data that will last for several more years. We can expect that most of the developments will be in computer-aided automatic data processing, in data handling and management, and in incorporating Landsat data into multiple source data. Although the multiple sampling statistical approach is not new, we are interested in adding in the satellite data to reduce the error factors in multistage sampling.

The most significant change, also a major roadblock, associated with Landsat-based remote sensing technology is its impact on the "way-things-are-done." For the new technology to be effective, the level of decision-making must be changed from small field units to large regions because of the nature of the information obtained from remote sensing. That change in the decision-making policy is hard to accept; but until it is, remote sensing will not become the effective tool that it can be.

I see this change being made in several subtle ways. For instance, the Forest Service is making a study of the dead-timber reserve in the Rocky Mountains as an alternative source of timber. These dead but usable trees constitute a large portion of all the available timber in the Northern Rockies, but they are spread out over several states. Individuals have always known that there were a lot of dead trees around in the forest; however, at the local decision-making level, the total potential of this situation was not acted upon. Now, by using optical bar panoramic cameras flown by a U-2 aircraft at 18.30 km (60,000 feet) altitude, large areas of the Rockies are being studied to determine the true potential of the scattered dead timber. The methodology for the Western Dead Timber Study that was developed at the Forestry Applications Program in Houston is now being evaluated by regional personnel in the Forest Service.

The Spruce Budworm Control Project in the Northeastern United States has turned to an application of computer-aided digital processing of Landsat data for assistance. Experience has shown that the flight crews of the large spray aircraft cannot turn the insecticide spraying



devices on and off while operating under the flight conditions required for low-level spraying. An inertial guidance system is being developed by the University of Maine to automatically meter the insecticide. This system needs to know which areas require spray application. To achieve this, Forest Service personnel are preparing a computer-aided vegetation map of Maine. Even with its inherent inaccuracies, the Landsat-based map will be better than what now exists. By knowing when not to spray, the Spruce Budworm Control Project will save \$280,000 in spray this summer. Also, the program will be able to comply with environmental constraints by not spraying across water bodies.

I could go on with numerous examples of operational, developmental, or experimental uses of remote sensing in forest and range management. However, I want to conclude by stating that even though remote sensing has been operational in forestry since 1927, it will be performing its greatest service in the future when it begins to assist in a global program for monitoring food and fiber. We expect to use the capabilities of remote sensing technology to analyze and manage data through computer-aided systems for some of the work now being done in other ways; however, the real benefits will come in the applications to meet new, broader-based inventory needs.

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## LANDSAT AND OTHER SENSOR DATA FOR LAND-USE PLANNING IN THE BALTIMORE AREA

James Manley  
*Regional Planning Council  
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### AIRCRAFT SENSOR USE

In the last 4 years, the Regional Planning Council (RPC) has been making wider use of the potential data from sensor activities. During 1973-1974, a detailed inventory was prepared of the existing 1973 urban land use in the 3578 km<sup>2</sup> (2250 mi<sup>2</sup>), six-county region that the Council represents. Using 1:24,000 scale transparencies from a high-altitude flight of March 1973, nonprofessional photo interpreters identified 12 land uses for developed land. Color-coded land uses were placed on mylar base maps prepared by the Maryland State Highway Administration. These areas were planimeted and aggregated by watershed and Regional Planning District. In spite of the map scale, the lack of professional photo interpreters, and the varying degrees of verification of the actual land uses, the maps and the summaries have been an invaluable tool to planners in the region.\* An accompanying report was prepared for the remaining undeveloped land by zoning type. In late 1974, a second project was started to produce data on changes in land use for the period 1964-1973, using additional air photos obtained for 1974 and 1970. The 1973 inventory was checked to determine development changes.† By a similar technique, airphotos for October 1975 were checked against the 1973 inventory to update the development land data.

### LANDSAT SENSOR USE

In early 1976, it was realized that the RPC's 208 Water Quality Planning Grant required a detailed, up-to-date knowledge of the land cover and use for the nonpoint source runoff models, in addition to knowledge of soil type, slope, etc. It was hoped that the National Aeronautics and Space Administration (NASA) Landsat Program would be able to provide the land-cover data needed, especially in the underdeveloped areas of the region. Investigations of the current uses of the Landsat sensor data revealed that there still were no successful uses of Landsat data in identifying specific urban uses (other than densities of residential use, paved areas, and roof tops). Therefore, it was decided to merge the information on developed land uses from the air photo interpretation and the land cover from the Landsat sensors. It was expected that this would give the most accurate results by taking results from each technique when they were best.

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\*"1973 Landuse and Zoning Patterns in the Baltimore Region," RPC Technical Memo 17 and 17- Appendixes, April 1975.

†"Land Development Changes 1964-1973," RPC Technical Memo 19, January 1976.

A goal of the 208 Project is to raise the level of local government expertise in data collection procedures, modeling, etc., when practical. A number of systems are available for processing Landsat and other sensor data, and an evaluation was made to determine how well they could meet the needs and goals of the 208 Project. The Intralab Division at NASA/Goddard Space Flight Center\* uses the ORSER (Office of Remote Sensing and Environmental Research) System from Penn State University to process a variety of sensor data and offered to train the 208 staff in its use. The cost advantages of the "remote-batch" system over those of a number of commercial "on-line" systems are very apparent. This approach gave the 208 staff the "hands-on" ability to process future dates as they became available with fewer contractual problems and significant cost savings. Although the questions of level of detail and reliability have yet to be compared, it is anticipated that there will be more detail and higher reliability with the off-line systems. Preliminary results confirm that, without considerably greater effort, urban land-use breakdowns will be limited to two residential densities, tree cover, asphalt, concrete, grass, vacant, water, and buildings. Outside of urban areas, the preliminary results indicate that there will be information on coniferous and deciduous tree cover, corn fields, other agricultural field types, pastures, scrub brush, sand and gravel, two more residential densities, and disturbed ground. (See table 1.) The data cell size is approximately 60 by 70 meters (1 acre).

The preliminary output of the Landsat Project at RPC has already spurred investigations into other types of studies that might be helped by using Landsat sensor data via the ORSER system:

- Change detection (suburbanization, farm conversions, tree cuts, and land filling)
- Pollution monitoring (air, water)
- Weather effects (Hurricane Agnes, etc.)
- Tree cover by species

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\*Intralab Brochure, NASA/Goddard Space Flight Center, 1975.

Table 1  
Regional Planning Council  
Landsat Cover Types\*

Cover Name	Symbol	Categories									Water
		Urban	Paving	Tree	Coniferous	Deciduous	Short Grass	Tall Grasses	Vegetation	Bare Ground	
Deep water	W										95
Shallow water	T										95
"Water"	S			35					10		50
"Water"	W			50					20		25
Gravel-quarry	8									95	
Disturbed ground	D									95	
"Bare"	V * Z *			10					10	75	
"Bare"	KL			5					5	85	
"Bare"	J			10					35	50	
"Urban"		20		5					70		
"Urban"	#	20		65					10		
"Urban"	A	10	5		70				10		
"Urban"		10	5			70			10		
"Urban"	F	75	20								
"Urban"	X	50	15	20					10		
"Urban"	Y	50	25	10					10		
Paved	I		95								
"Paved"	=	20	40	5				30			
Grass	-						95				
"Grass"	I			20			80				
"Tall grasses"	9			20				75			
"Tall grasses"	5			10				85			
"Tall grasses"	6			5				90			
Gum/poplar	G					95					
White oak	O					95					
Maple/gum/oak	M					95					
Sycamore/ash	H					95					
Pine	P				95						
"Pine"	R				75				20		
Corn	C								95		
Field 2	2								95		
Field 3	3								95		
Field 4	4								95		
Field 5	5								95		
Field 7	7								95		

\*Cell numbers represent percentages in each category (95 percent maximum)

1875

## REMOTE SENSING, GEOLOGY, AND LAND USE

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### INTRODUCTION

Perhaps, I would not be overstating my case too much by postulating that geology is the cornerstone on which land use is or can be determined. Illustrations abound. The characteristics of the underlying bedrock determines, to a large extent, the topography of the landscape, the thickness and fertility of the soils, the availability of ground water, the suitability for disposal of solid and liquid wastes, the location of mineral and mineral fuel deposits, the availability of construction materials, the location of rivers and streams, the potential for geologic hazards, and a host of other primary and secondary interrelationships between man and his environment. Geology has played a role in the location of the major cities along the eastern seaboard because most major cities, from New York City to Raleigh, North Carolina, were sited on the Fall Line, a geomorphic feature that marks the contact between the unconsolidated sediments of the Coastal Plain and the crystalline rocks of the Piedmont. This feature determines the head of navigation of the coastal rivers and estuaries and also determines the locations of falls that furnished water power for the early colonial industries.

The geologic map is one of the most useful products of geologic research. It depicts in a two-dimensional picture the distribution and three-dimensional relationships of geologic formations. Geologic mapping, however, is not a one-time operation; rather, it goes through an evolutionary development in periodic pulses based on the state of the art, availability of new tools and instruments, and new geologic insights. Let me illustrate by reference to the evolution of the geologic map of Maryland. The first geologic map of Maryland was published in 1859 at a scale of approximately 1 inch = 10 miles (1 cm = 6.3 km). Although, by present standards, this appears to be a rather primitive effort at depicting the geology of the state, it nevertheless represents a tremendous achievement of geological insight. The next two geologic maps of the state appeared in rather rapid succession: one in 1898 and the next in 1906. These maps represented a great advance over the 1859 map in that they more accurately depicted the distribution of the formations, and, for the first time, geological formations were named for their type area of exposure. The scale was enlarged to 1 inch = 8 miles (1 cm = 5 km). It was not until 1933 that the next geologic map of Maryland appeared at a scale of 1 inch = 6 miles (1 cm = 3.8 km). This map also represented a more detailed map but did not represent a large departure from the previous maps. The latest geologic map of the state was published in 1968 at a scale of 1:250,000 (1 inch = 4 miles; 1 cm = 2.5 km). Although this is also an advance over the previous maps in terms of scale and in terms of geologic interpretations, it

hardly represents the ultimate in terms of representing the geology of the state. Indeed, it is one characteristic of a geologic map (and the nature of research) that it is almost out of date at the time it is published. About the best we can say is that it represents the state of knowledge at the time of mapping and compilation. While these statewide geologic maps were being prepared, even more detailed geologic mapping was accomplished. For a time, 1 inch = 1 mile (1 cm = 0.6 km) county geologic maps were considered to be detailed enough for most purposes. Now the Maryland Geological Survey is mapping on a scale of 1:24,000 (1 inch = 2000 feet; 1 cm = 240 m) because that detail is necessary to depict resources and certain environmental constraints based on the geology of an area.

What are the basic tools of a field geologist who manufactures these multicolored geologic maps? They are (and have been for many decades) a good pair of field boots, a Brunton compass, a geologic pick, a hand lens, notebook and pencil, and a keen and fertile geologic imagination. No adequate substitute has yet been developed for examining rock exposures in the field. This is not to say that new tools and new methods have not been developed over the years that supplement and complement the basic tools described previously. The advent of exploratory drilling techniques has greatly expanded the geologist's knowledge of the subsurface and has provided a test for his models of subsurface structure inferred from surface mapping. In like manner, the petrographic microscope, various X-ray techniques, and geochemical tests have provided new insights into the mineralogic and chemical composition of the Earth's crust. Another category of techniques and tools that I will lump under the broad category of remote sensing has also been invaluable to the geologist in gaining new insights into the nature of the history of the Earth and its mineral wealth.

### GEOLOGICALLY RELATED REMOTE SENSING TECHNIQUES

Remote sensing is a term that has found its way into the technical literature relatively recently. Most people associate the term with aircraft or satellites using highly sophisticated scanning devices to map certain features of the Earth, Moon, and planets. Use of these devices has greatly accelerated our knowledge of the physical features of remote areas and has added important new information about those areas that have been mapped in some detail using more conventional methods.

On the other hand, remote sensing in the Earth-science disciplines is not a new concept. Seismometers of varying degrees of sophistication have been used for centuries to measure earthquakes. Seismic methods using explosives or other acoustic sources have been used for about 5 decades. Similarly, measurements of radioactive properties, magnetic properties, electrical properties, and gravity of the Earth have been carried out for many years, both from on-ground measurement and from aircraft and water-borne platforms. Aerial photography has also been an invaluable tool to the Earth scientist for a number of decades.

All of these remote sensing methods are perceived by the geologist as tools that provide some additional clues on the structure, composition, and spatial relationships of the Earth's subsurface.



These techniques should not be viewed as a substitute for the traditional methods of geologic mapping. The term "ground truth" has been introduced into the literature surrounding remote sensing. Field geologists have been engaged in obtaining "ground truth" for over a century, but all the while they thought they were mapping geology!

The following remote sensing techniques have been used to supplement our knowledge of the geology of Maryland:

- Aerial photography (black and white, color, false color, infrared)
- Seismic (3.5- and 7.0-kHz transducers, 700-joule minisparker, Vibroseis (TM))
- Magnetic (statewide coverage by airborne magnetometer)
- Gravity (selected areas of gravity mapping)
- Radioactivity (selected areas of airborne radiometric surveying)
- Down-hole geophysical logging (predominantly electrical resistivity and gamma ray)
- Landsat-1 and -2 and Skylab supplemented by aircraft imagery

The remote sensing methods that have the most immediate application to the Earth-science aspects of the Chesapeake Bay region are seismic, magnetic, down-hole geophysical logging methods, and aircraft and satellite imagery. Gravity and radioactivity measurements are helpful as supplementary methods.

## **APPLICATION OF REMOTE SENSING TECHNIQUES**

### **Chesapeake Bay**

As an aid to geological interpretations, remote sensing becomes more critically needed where the geology is obscured by a covering medium such as vegetation or water. For example, it is impossible to map the bottom of the Chesapeake Bay by direct observation. This is one of the reasons why this large area of the state is more or less unexplored even today. The Maryland Geological Survey is embarked on a program to map the Bay bottom, using a variety of direct observational and remote sensing techniques (Chesapeake Bay Earth Science Study). Grab samples of sediment will be taken on a 1-km grid; gravity cores and vibratory cores will be taken on a broader grid spacing. Bottom sediments will be mapped on the basis of their size classification and their mineralogical, chemical, and biological composition. To supplement these direct observations, several shallow seismic reflection profiling techniques will be used, including 3.5- and 7.0-kHz transducers and a 700-joule minisparker. Over 900 km of subbottom profiling have been done to date. These methods give valuable data on the location, depth, and orientation of paleochannels (sediment-filled ancient river channels) beneath the Bay bottom and will give important new insights into the geologic history of the Bay. From a more practical standpoint, delineation of paleochannels beneath the Bay may point to their continuation beneath the land areas of the Eastern Shore. Because one of these

sediment-filled channels has already been identified in the Salisbury area as a prolific ground-water source, additional paleochannel discoveries may add significantly to the ground-water resources of the Eastern Shore.

Side-scan sonar and deep seismic profiling are two other remote sensing techniques that could add significantly to the geologic baseline data of the Chesapeake Bay. As demonstrated in several pilot areas, side-scan sonar seems to be capable of delineating oyster bars and current features in the bottom sediment, and, to some extent, discriminating between sediment types (mud versus sand). Deep seismic profiling is important in correlating geologic formations on the Western Shore with the same formations on the Eastern Shore. Although our present project does not include the latter two techniques, we are hopeful that we may obtain this capability in the future.

Airborne and satellite remote sensors have been and will be used to identify near-shore bottom-current features. They are also valuable in monitoring long-term erosion along the Bay and ocean shorelines and in identifying short-term sediment migration patterns.

### **Continental Shelf**

In the past decade, many thousands of kilometers of common depth-point (CDP) seismic reflection lines have been shot on the continental shelf off the United States. Whereas most of these surveys were done under contract to segments of the oil industry and are thus confidential, some lines have been surveyed by the U.S. Geological Survey (USGS) and are in the public domain (USGS, 1975). Seismic reflection profiling is capable of depicting seismic reflection properties and configurations 10,000 meters or more beneath the surface. Interpretation of these profiles gives an insight into the structure of the subsurface rocks, their composition, and degree of consolidation or cementation, and inferences can be drawn concerning the depositional history of the basin being surveyed. Ground-truth data obtained by drilling and subsurface sampling are necessary to refine and quantify more accurately the interpretations made from the seismic profiles.

A consortium of oil companies drilled a stratigraphic test well (COST B-2 Well) in Baltimore Canyon trough in early 1976. The well, located 126 km (78 miles) east of Atlantic City, New Jersey, was drilled in 58 m (190 feet) of water to a total depth of 4890 m (16,043 feet). Samples of the sedimentary rocks encountered in the hole were retrieved and studied, and numerous types of down-hole geophysical logs were run. This well represented the first "hard" data on the characteristics of the deep subsurface of the Atlantic continental shelf off the U.S. shoreline. Moreover, it provided the ground-truth data for calibrating the many kilometers of seismic reflection profiles that were surveyed on the mid-Atlantic outer continental shelf. In this connection, it is interesting to note that very good correlation was noted between the time-depth curves derived from a seismic reflection line run in 1973 and the down-hole sonic log in the COST B-2 Well (USGS, 1976). This kind of agreement between remotely sensed data and "ground truth" gives the exploration geologist and geophysicist added

confidence in his interpretation of remotely sensed data. Without the benefit of seismic reflection and refraction, it is almost a certainty that we would not have large production of oil and natural gas in the Gulf of Mexico, and the success ratio of finding oil and gas on land would be severely reduced.

### **Land-Based Remote Sensing**

In addition to assisting in the exploration for oil and gas, remotely sensed geophysical properties have many other applications. Some applications were illustrated in the previous discussion on the Chesapeake Bay Earth Science Study. The Maryland Geological Survey has conducted land-based continuous seismic reflection profiling using the Vibroseis (TM) technique. The purpose of this profiling was to establish better data on the thickness of Coastal-Plain sediments and to determine the presence or absence of faulting in basement rocks and the overlying sediments (Jacobein, 1972). These data are important in determining the geologic framework for identifying potential ground-water aquifers and in establishing the location and relative age of faults in proximity to potential power plant sites.

Various down-hole geophysical logging techniques are used on a routine basis to support the hydrogeological investigations conducted by the Maryland Geological Survey in cooperation with the U.S. Geological Survey. These techniques are invaluable in determining the subsurface geologic framework and the hydrologic properties of aquifers (Hansen, 1967). It may be stretching the point somewhat to include down-hole geophysical logging in the general category of remote sensing, but these techniques, although they require a sensor in close proximity to the environment that is being measured, record various physical properties at a remote location. Electric logging is perhaps the down-hole method most often used in ground-water exploration. Electric logs record both electrical resistivity and potential characteristics of the surrounding geological strata. Interpretation of the electric log gives data on not only the type of strata encountered but also the nature of the contained fluids (e.g., fresh water, brackish water, and saltwater). With experience, the logs can be interpreted to distinguish between a potentially good or poor aquifer. Thus, the electric log and other down-hole geophysical techniques represent valuable tools for use in the exploration for ground water. However, it should be emphasized that it is a tool, not a panacea. Properly used, down-hole logging must be used as a supplement to other geological methods of information retrieval (e.g., geological mapping, sampling of subsurface sediments, and pumping tests).

### **Airborne Remote Sensing**

Aeromagnetic surveys have been completed for the entire state of Maryland. Maps resulting from these surveys are useful in interpreting geological relationships between rock units and give some insight into the characteristics of basement rocks that are deeply buried beneath the Coastal-Plain sediments. Aeromagnetic maps depict the total intensity magnetic field of the Earth in gammas. The data are contoured along lines of equal magnetic intensity. Because different rock types have different magnetic susceptibilities based on their mineralogical

composition, geological formations can usually be differentiated on the basis of their aeromagnetic "signature." The magnetic properties of rocks can therefore be used as an aid in geologic mapping, particularly in areas where the rocks are obscured by a thick cover of overlying sediment or regolith. For example, Coastal-Plain sediments increase in thickness from 1 m at the Fall Line to more than 24.40 m (8000 feet) at Ocean City; yet, it is possible by judicious use of aeromagnetic maps to speculate on the composition of the deeply buried basement rocks beneath the sediments. Aeromagnetic surveying has also been successfully used to find ore bodies (mainly magnetite) and as an aid in oil and gas exploration.

Geologic ramifications of remote sensing from aircraft and satellite platforms have been addressed in Maryland. The Maryland Geological Survey participated as a principal investigator in the ERTS-1 (Earth Resources Technology Satellite) and Skylab Programs. The purpose of our project was to relate remotely sensed images to various types of geological problems using visual observations of the imagery (Weaver, 1974 and 1975). Features such as fold culminations, linear belts of geologic units, and contacts between geologic units in local areas could be discriminated. Shoreline and near-shore features such as beaches, beach ridges, marshland, and turbidity patterns were recognized.

Digital data processing of Landsat computer-compatible tapes has been used to map mining activities in Maryland (Anderson and Schubert, 1976). Although the method was used for mapping disturbed areas related to coal mining, the method may also have application to the mapping of other activities, such as sand and gravel extraction in the Chesapeake Bay region. Digital data processing represents a potentially powerful and economic technique for monitoring relatively large-scale changes in land-use patterns.

It should be pointed out that geologic features that can be recognized on satellite and aircraft imagery can be either accentuated or obscured by land-use patterns. For example, the Frederick Valley shows up very clearly on the Landsat images because of intense agricultural land use in this area. This signature in turn permits one to approximate the area underlain by limestone because the bedrock lithology has largely determined the soil types in this area. On the other hand, although the Middletown Valley has a Landsat signature similar to the one for the Frederick Valley, it is not underlain by limestone. It illustrates the point that can be made about all remotely sensed data: namely, that erroneous conclusions can be drawn from the data if one does not have sufficient onsite physical data (ground truth). Moreover, the interpreter of remotely sensed data is responsible for clearly differentiating between purely speculative conclusions based largely on remotely sensed data and those conclusions that are based on site-specific data supported or corroborated by remotely sensed data.

## CONCLUSIONS

Geologic maps provide one of the primary inputs into land-use planning. The geology of an area determines to a large degree slope and topography, ground-water availability, suitability for waste disposal, mineral resources, thickness of soils, geologic hazards, and other primary and secondary relations between man and his environment.

The geologist uses a variety of tools in mapping the geology of an area. Remote sensing is one of those tools. But, the geologist has perhaps a broader concept of remote sensing than some other disciplines because he has used aerial photography and seismic, magnetic, gravity, and radioactivity techniques for many years as aids in geologic mapping and in exploration for minerals and mineral fuels. He looks upon the relatively new technique of aircraft and satellite remote sensing as an additional and welcomed tool that can help him better understand the three-dimensional nature of the Earth's crust.

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## MARYLAND AUTOMATED GEOGRAPHIC INFORMATION SYSTEM

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The Maryland Department of State Planning established the Maryland Automated Geographic Information (MAGI) System in April 1974. The MAGI is a computer-based system designed for storing geographic data in a consistent and coordinated manner. The data are stored, retrieved, and analyzed using a 400 km<sup>2</sup> (91.8-acre cell, 2000 by 2000 ft). The information stored in this system can be displayed on computer maps in a manner similar to standard map graphics. However, unlike a normal mapping system, the structure of the MAGI system provides many advantages for complex information studies that involve massive amounts of data. Through access to the Univac 1108 computer system at the University of Maryland, the data bank contains the following useful information for performing land-use analyses:

- Natural soil groups
- Geology
- Slope
- Mineral resources
- Aquifers
- Surface-water quality
- Bay bathymetry
- Natural features
- Vegetation
- Water and sewer service areas
- Highway networks
- Transportation facilities
- Public properties
- Historic sites
- Existing land use
- Watersheds
- Electoral districts
- County-comprehensive plans

These data were compiled from a variety of existing source material. In almost every case, several sources were referenced, and the data were compiled and mapped on a standardized county base. In the example of natural soil groups, an extensive data aggregation (from county soil maps) and remapping program was accomplished with technical assistance and supervision from the State U.S. Department of Agriculture Soil Conservation Service Office.



In another example, high-altitude aircraft photography was interpreted to establish the first statewide land-use inventory. Data-use manuals were prepared for: natural soil groups, geology, minerals and aquifers, slope, forest vegetation, public-owned land, land-use, and natural areas. These manuals have been circulated, together with the data maps, in support of other planning efforts and in a manner that augments MAGI.

The capability of the MAGI system to provide a quantitative framework for rapid data retrieval, combination, comparison, and analysis permits it to serve many of the informational needs of local, regional, and state agencies. According to the U.S. Department of Interior, Office of Land Use and Water Planning, the MAGI system has the most comprehensive capability for the storage, retrieval, manipulation, and display of geographic data of any system currently existing on a statewide level.

During 1976, the MAGI system was used by the Department of State Planning in the State Land-Use Planning Program. Specifically, the MAGI system was used to prepare maps reflecting proposed policies for the conservation of the State's natural resources, and for the allocation of orderly patterns of future settlement and growth. In conjunction with this effort, the Department of State Planning became a "principal investigator" in the Earth Resources Technology Satellite (ERTS) Program sponsored by the National Aeronautics and Space Administration (NASA). In 1975, it published a document, entitled, "Investigation of Application of ERTS-1 Data to Integrated State Planning in Maryland," that discusses the potential for interfacing remotely sensed data with the MAGI System.

This report to NASA also documents hardware improvements necessary for making them more useful for State planning purposes. For example, the Department tested the use of Landsat computer-compatible tapes in monitoring bare ground as an indicator of development and a host of related physical and environmental factors. Higher resolution capabilities would greatly improve the accuracies of such a routine.

Other significant uses of the MAGI system during 1976 included:

- Preparation of maps identifying the habitat potential for wild-turkey introductions for the Maryland Wildlife Administration
- Preparation of maps showing potential soil and commercial species productivity for the Maryland Forest Service
- Preparation of maps and summary listings of septic-system capability and liquid-waste disposal capability for the Maryland Environmental Service
- Preparation of maps identifying present and probable uses of the State's prime agricultural soils for the Maryland Department of Agriculture
- Preparation of maps used in evaluating the environmental impact of proposed highway realignments for the State Highway Administration.



While providing technical assistance to the State Highway Administration, the Department projected the software that permits the development and integration of smaller cell sizes with the current MAGI data base. In several instances (for State Highway, Baltimore County, and Department of Natural Resources), small area—20 km<sup>2</sup> (4.5-acre) cells—data bases are being constructed.

Effort is being contributed to a new study being conducted for the Energy and Coastal Zone Administration. This study will involve a regional screening for selecting potential sites for major public and industrial facilities in the Coastal Zone.

Although the complete capability of the MAGI System is yet to be realized, its use during 1976 demonstrated that the MAGI system is a dynamic tool with the capability of servicing the information requirements of planners and decision-makers.

4000 1000

## THE CHESAPEAKE BAY: A CHALLENGE TO THE REMOTE SENSING COMMUNITY

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### BACKGROUND

We are drawn together here by a common bond and under the banner, "Application of Remote Sensing to the Chesapeake Bay Region." I hold that within this assembly there is a body of knowledge that can be used to identify problems and recommend solutions that not only will have impact on the Chesapeake Bay Basin but could also have significant recognition beyond the shores of this nation.

I contend that within the grasp of this group is an opportunity to participate in a major breakthrough in the art of remote sensing. Note that the term "art" differs from science—science being the product of predictable occurrences and art being the product of value judgment.

Time and space permit neither the enumeration of the achievements of remote sensing nor of its failures. I ask only that you recall that they are many. I intend to simply highlight the potential of the technology that brings us into conference, to reflect on the beauty and the importance of the basin upon which we intend to focus our efforts, to acknowledge the capabilities of the participants, and to propose a synergistic course of action.

### The Tools

As a common point of departure, I assume that we all appreciate the high potential of sensing from satellite and aircraft as being the most expedient and cost-effective technique available for monitoring many geographical areas of significant size. It provides not only a synoptic view from vantage points that are unique, but also an unequalled record for change detection when used with repetitive cover. Combined with responses available throughout the electromagnetic spectrum, these viewing characteristics provide a record unequalled by visual observation.

We now have access to data from several existing satellite systems that periodically cover the Bay, and other satellites are under development. In addition to satellites, a wide variety of aircraft operate in the Bay area. The National Aeronautics and Space Administration (NASA) has U-2's that occasionally operate in the area. The Department of Defense has aircraft that range from the high-altitude SR-71, Navy F-8's, and Army low-level observation types. This family of aircraft systems is augmented by aircraft of other government agencies and civil contractors. These systems provide a full range of remote sensing technology.

## THE CHALLENGE OF THE BAY

The importance of the Bay as an entity of environmental interest is beyond reproach. In the early 1600's, a small fleet entered the Chesapeake Bay, and its Captain, John Smith, declared that "heaven and earth seemed never to have agreed better to frame a place for man's commodious and delightful habitation." History is replete with subsequent praise of the beauty and bountifulness of the Bay.

I personally have enjoyed the grace of the Bay for more than a half century, and I am in complete agreement with one who described the Bay as a "place beautified by God with all of the ornaments of nature and enriched by his earthly treasures."

Aside from its beauty and economic importance as a commercial and recreational asset, its size and character make any meaningful monitoring program a task of considerable magnitude. To understand the Bay as a system, it will be essential that a remote sensing program include all of the land mass in the basin and all of the rivers, streams, and estuaries that serve the basin.

Although as a body of water, the Bay is only 269 km (167 mi) long (less than the coverage of a couple of Landsat images), its surface covers 11,137 km<sup>2</sup> (4300 mi<sup>2</sup>). Whereas some parts of the Bay are more than 30 meters (100 feet), many square kilometers of tidelands are shallow enough to be ideal for the shellfish industry. Thus, its average depth is only about 6 meters (20 feet), but, within its 8045 km (5000 mi) of shoreline, it contains 70,041 billion liters (18,500 billion gallons) of water.

The interest of many students of the Bay is confined to small segments of the total system. However, it is only within the framework of understanding how the 48 principal rivers drain more than 181,300 km<sup>2</sup> (70,000 mi<sup>2</sup>) to feed and interact with the total Bay system can a real appreciation of the problems be addressed.

## THE PROBLEM

We meet here with the purpose of promoting the use of remote sensing in studying, monitoring, and understanding the Chesapeake Bay. Although it can be expected that these deliberations will contribute to many of the individual projects now being conducted, without some effort to join forces and coordinate our activities, the contribution to understanding the Bay as a total system will be wanting.

There is little doubt that the technology exists to survey, model, analyze, and predict many of the perturbations and vacillations of this magnificent basin. The primary constraint is that we must understand and appreciate the limits of our capabilities. Singly, they are miniscule; collectively, they are less than adequate. We must also keep in mind that a meaningful program to monitor the Bay is not an overnight endeavor; and, without a comprehensive plan, it cannot start tomorrow, and it cannot be completed in a short span of months or even years. A meaningful monitoring and remote sensing program for the Bay will probably require

a decade. Even then, success will require that the remote sensing community join forces and support others who are responsible for making decisions regarding environmental quality. Let us not forget that remote sensing is not an end in itself, but only one facet of the many disciplines—all of which must be brought into focus to plan and conduct a successful program.

Even if all agencies who have expressed profound and provincial interest in the Bay could, by some miracle, work collectively and at near 100-percent efficiency, the size of the effort, compared to the magnitude of the task, would leave much to be desired. The critical issue here is how do we make maximum use of the limited resources that are available.

### REMOTE SENSING LIMITATIONS

The purpose of this paper is to encourage and promote the legitimate use of remote sensing systems. It must be recognized that remote sensing is not a panacea. Furthermore, remote sensing severely suffers from being oversold. Although the technical literature abounds with research data, theoretical applications, and feasibility demonstrations, the full potential of remote sensing technology in actual operational programs is not evident. Moreover, much of the data are of questionable validity, and all too frequently are accepted with reluctance and skepticism. This is not without cause. I recall an instance in which one scientist procured two instruments that were developed by another government agency, conducted some superficial tests, found some random correlation, and then proceeded to present papers on the new-found technology. He even traveled as far as Japan spreading misinformation. The subject was then dropped, the equipment was scrapped, but the papers remain to mislead some trusting environmentalist.

As proponents, we must ask ourselves: Where is a reliable source of information by which the scientist, engineer, or technician not experienced in remote sensing systems can seek direction?

- How does one quantify the movements of cooling waters being emitted from a power plant through use of a thermal scanner?
- What is accepted as a standard reference for studying current movements using the combination of dye tracking and remote sensing recording?

We know that the feasibility of conducting many of these operations has been demonstrated. Yet, even the most elementary remote sensing techniques are not being used in many programs that need support. I believe that the majority of the environmentalists have not benefited from the developments in remote sensing technology. Is there any community endorsement of our methods or procedures? Where are performance standards? What are maximums and minimums for acceptable data? For example, is there agreement on a position reference system? Should we use latitude and longitude, Geo-Ref., or Universal Transverse Mercator (UTM)? After that is settled, we should agree on a vertical reference. Should we use feet in reference to sea level, or should we go "Mod" and use meters? Without standards, how can data collected by different agencies on different parts of the Bay be integrated into a meaningful study of the Bay as a total system?

### AN APPROACH TO THE PROBLEM

The literature abounds with references to multispectral scanning, laser techniques, infrared, microwave, and radar. These are analyzed with multidimensional models, digital analysis, and holographic projections. Although feasibility has been proven, only a minimum of effort has been devoted to reducing these sophisticated technologies to operating practice for environmental applications.

In the environmental movement, most scientists are engaged in solving specific problems related to specific locales. Little effort is being devoted to the more general problems that are often amenable to solutions identified through use of remote sensing technology.

How do we encourage the limnologist, the forester, the urban planner, and a host of others to make frequent and regular use of remote sensing technology? Is standardization the name of the game?

Why not take a page from the book of the scientists and engineers who are engaged in making military weapons? The military pioneered most of the remote sensing technology we now apply to environmental science. Hardly a single facet of remote sensing technology has not been investigated by the weapon makers. Multispectral, false color, laser, microwave, infrared, and radar; low-altitude, high-altitude, and space systems are all tested, evaluated, and calibrated for the purpose of recording the environment of a selected target or area of interest. To gain confidence in the capabilities of these tools and to train others in the use and value of these tools, the military scientist establishes operating maxima and minima. To develop these parameters of confidence, the military uses a range with a multiplicity of targets designed for the specific purpose of evaluating and demonstrating specific capabilities of the tools of their trade.

Where in the framework of remote sensing do we find criteria or standards accepted for operational applications? Is this a void in our efforts to apply remote sensing tools?

We have the tools but we do not have a remote sensing range that is calibrated for the specific purpose of demonstrating operational capabilities or developing standard operating procedures that will produce data that have an acceptable degree of confidence.

For instance, let us look at a concept of an environmental range with dynamic targets specifically selected for evaluating and demonstrating remote sensing technology as it applies to environmental problems. What type of targets would be required in this range? A few are water, land, air, agriculture, industry, and urban areas.

Where within the 9 million km<sup>2</sup> (3.5 million mi<sup>2</sup>) of the continental United States is the most suitable geographic location to establish a remote sensing range with the following desired characteristics.

- Long enough to include a wide range of climatic contrasts

- Oriented in general North-South direction to make maximum use of satellite systems in polar orbit
- Small enough that a total drainage basin can be studied as a system
- Near enough to major remote sensing activities to encourage wide participation (Langley Research Center, Goddard Space Flight Center, Environmental Photographic Interpretation Center (Environmental Protection Agency), and the Corps of Engineers)
- Has enough *in-situ* monitoring activity to provide ground truth
- Has a working scale model to support hydrolic studies
- Has political importance and support?

The answer is, of course, the Chesapeake Bay Basin.

### PARTICIPANTS

To some degree, most agencies now participating in Bay programs have specialized capabilities in environmental studies. On the other hand, it is doubtful if any agency has a complete complement of capabilities. Some agencies (such as NASA and the Environmental Protection Agency (EPA)) have special capabilities in remote sensing; others (such as the Smithsonian Institution and the Virginia Institute of Marine Sciences) are more oriented toward surface sampling and analysis. These and many other agencies that are active in studying the Chesapeake Bay have similar objectives, but most often their facilities, capabilities, and areas of interest are distinctly different. How do we marshal these assets? Should not a first step be an inventory of the capabilities that are available?

The EPA Remote Sensing Laboratory has the potential of making a significant contribution to the Chesapeake Bay Program. Its monitoring systems include multispectral and thermal scanners, lidar, airborne air and water sampling instruments, and many of the more conventional devices. The primary objective of this laboratory is to test, evaluate, and demonstrate the effectiveness of remote sensing systems with the end objective of providing the tools that EPA regions, states, and local communities can use to monitor and protect the quality of the environment. It is within the scope of this objective that the concept of creating a remote sensing range in the Chesapeake Bay area has been addressed. After all, if the capabilities of a system cannot be proven under known conditions, should it be endorsed or encouraged for general use?

Some of the EPA Remote Sensing Laboratory capabilities are located at the EPA Environmental Photographic Interpretation Center (EPIC) at Warrenton, Virginia. This laboratory is responsible for supporting much of the EPA activity in the eastern part of the country. It also functions as the EPA interface with other federal agencies that are active in remote sensing programs. Many of these activities are related to programs in the Chesapeake Bay basin. Some of the programs could probably be modified to meet the requirements of

agencies that specialize in *in-situ* sampling. This kind of interaction would probably improve the effectiveness and validity of both program areas.

EPIC has a full complement of photographic processing and production equipment and the support of highly trained analysts with sophisticated viewing and mensuration devices. These facilities and experience could probably be made available to agencies and organizations that participate in Bay programs. EPIC also has a broad selection of cameras and scanners of various characteristics that could probably be loaned to agencies for specific programs. In addition, EPIC maintains a library of remote sensing coverage for EPA and has access to the remote sensing records of other government agencies. By some mutual agreement, this service could be made available to agencies that participate in Bay programs.

For the purpose of illustration, I have only highlighted some of the capabilities that EPA could contribute to a cooperative program. The unique capabilities of other organizations (such as NASA, U.S. Geological Survey, etc.) are known to many of the participants in this conference. Would it not be to our mutual interest to undertake a pilot program to demonstrate the capabilities of our combined efforts?

## SUMMARY

The size of the Chesapeake Bay basin alone presents a formidable problem. The period of the hydrological, climatic, and biological cycles dictates that years, if not decades, of surveillance and analysis will be required to obtain validated data. To enter into a Chesapeake Bay environmental monitoring program without clearly understanding the dimensions of the problem in both the geographical area and the span of time, the data obtained will be of marginal value. Furthermore, an understanding of the problem without full recognition of the limitations in regard to resources and technology available can only lead to failure.

Neither the magnitude of the task nor the limits of our resources is reason for reluctance. We have within our grasp the potential, the experience, the knowledge, and the equipment to make a major contribution to the Bay area, and possibly a major contribution to the art of remote sensing, by demonstrating the application of standard operating procedures and how such technology could support a comprehensive plan for monitoring the Chesapeake Bay basin.

The scientific, engineering, and technical expertise of personnel in the agencies now participating in Bay activities have the technical competence to direct a coherent program. However, the mechanics of coordination, communications, and administration will require considerable study and effort.

How do we put these forces to work? I propose that an output of this conference be a recommendation that a task force—a planning group or some other forum—be convened, endorsed, and supported for the specific purpose of developing a plan of attack to resolve these problems that inhibit the acceptance of the technology we are here to promote.



## MISSION OF A REMOTE SENSING CENTER

Robert M. Ragan, Dixie A. Pemberton, and Thomas D. Wilkerson

*University of Maryland*

*College Park, Maryland*

### PROPOSAL

Faculty members interested in remote sensing propose that a Center for Remote Sensing be established. Provision for such a Center is included in the University of Maryland Long-Range Planning. This Center would:

- Provide service, research, and education in the developing discipline of remote sensing.
- Effect multidisciplinary linkages between scientists and other users of remote sensing and those who develop remote sensing techniques.
- Strengthen and extend existing University of Maryland remote sensing capabilities into a cohesive program.

### DESCRIPTION

An informal faculty group is interested in fostering education, research, and service in remote sensing of the environment. Through a questionnaire to departments and laboratories of the University of Maryland, the group has gathered information that helped to define University of Maryland interests and capabilities in remote sensing. Our goal is to facilitate the flow of information between groups that generate remote sensing techniques or need such techniques for environmental problems. This includes, as an important part, the exposure of students to the possibilities and limitations of remote sensing.

Experience shows that a given technique, such as aerial/orbital photography, is applicable to many problems, such as crop coverage, diseased or stressed vegetation, urban land use, shoreline erosion, water turbidity, and extent of strip mining. Many examples exist of instrumentation systems that can be applied to a variety of environmental problems. Thus, remote sensing emerges as a quasi-discipline that, to some degree, calls for education and training on its own merits. The methods of remote sensing are now quite diverse and include, as well as passive photography, "active" sensing by means of lasers and remotely operated nuclear excitation devices.

One of the prime objectives of this group is to provide visibility on remote sensing to the students regarding opportunities existing both on the campus and in the local vicinity.

Students interested in pursuing various aspects of this "field" would derive tremendous benefit from information that would be made available. Students can be made more aware of new and current techniques for detection and identification and their application in many environmental problems and potential solutions. In addition, this material can be used by students and faculty to generate new and advanced research programs, many of which may be difficult, if not impossible, to solve by more conventional techniques.

In addition, the Center would provide training and services related to state and local governmental units.

The service function would emphasize the maintenance of current data bases and assistance on the application of remote sensing technology to problem solution. The Center would maintain current high-altitude and conventional aerial photography files for the state. In the rapidly changing urban areas, the information on these photographs would be digitized annually and made available to users in the form of computer maps, statistical files, cards, or magnetic tapes. The Center would also maintain a set of current, geometrically corrected Landsat tapes that would provide seasonal coverage of the state or region. From this base of operations, the Center would be in a position to respond to special-request projects from local governments or state agencies needing remote sensing technology for environmental, water-resource, land-use, transportation, or general planning problems.

Although numerous research projects have proven that Landsat and other remote sensing platforms have important applications to problems facing state and local governmental units, acceptance of the technology has been slow. A major problem has been, and continues to be, a lack of understanding and opportunities for training in the user community. Thus, a viable Center would provide short courses at the University of Maryland designed for a community of users. These courses would be offered frequently, using facilities of both the Center and the established Center for Adult Education on the College Park Campus. Staff members would also develop workshops that would be given in the offices of the agencies. There would also be academic courses at both the undergraduate and graduate levels. The undergraduate course would be designed to introduce students in resource-related fields to the potential offered by the remote sensing technology. The graduate level courses would be offered in the evening to encourage practitioners in the field to attend.

In meeting this service and training responsibility, it would be anticipated that the state would assign and support a professional from each of several agencies to the University Center. For example, this might include the Office of State Planning, the Water Resource Administration, the Department of Transportation, and the Department of Natural Resources. These professionals would be trained by the staff of the University of Maryland and, in turn, would be the "extension service" personnel working with the state and local agencies. Two master's degree level assistantships could be supported by the various state agencies participating in the program. These M. S. students would work with the agency professionals and serve as technicians to make the services and training responsibilities of the Center a reality.

The Center would also function as an international service and training facility. In this capacity, the Center would offer academic courses for master's level personnel that would be taken by foreign students pursuing degree programs. The Center would develop short courses of several weeks duration designed especially for foreign personnel. These short courses would also be formatted to be given by a team at foreign universities or in major governmental offices. The Center would also aid foreign governments in setting up remote sensing interpretation systems and professional teams.

Finally, the Center could function as an international service organization by providing consultation for the solution of specific problems. These services would be offered on a contract basis to either the foreign governments or to organizations such as the Agency for International Development or the World Bank.

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## PANEL DISCUSSION

### PANEL

Robert M. Ragan, Chairperson  
College of Engineering  
University of Maryland

Philip J. Cressy  
National Aeronautics and Space Administration  
Goddard Space Flight Center

James R. Wray  
U.S. Geological Survey

Robert W. Douglass  
U.S. Forest Service

James E. Manley  
Maryland Regional Planning Council

Kenneth N. Weaver  
Maryland Geological Survey

C. Eugene James  
U.S. Environmental Protection Agency

John Antenucci  
Maryland Department of State Planning

### PROCEEDINGS

*RAGAN:*

There is a wide array of questions. Some of them are overlapping; some of them are extremely broad.

We've chosen to begin the session by asking each panel member to respond to a couple of specific questions.

I would also like to open the discussion to audience participation. We'll try to get through the questions, but have some audience participation at the same time.

We'll open with some comments by Bob Douglass—he has some fascinating ideas that he raises in his abstract.

*DOUGLASS:*

One thing has come to my mind as I've looked over the group. I know a lot of you from reputation, and I want to ask a question: how many in this group represent management of land? How many actually make the decisions on managing land?

(A showing of hands)

*DOUGLASS:*

Okay, there are four of us. I wanted to point that out because there's a little skew approach here that is good in a way, but I wanted to point out the fact that, when the speakers say "managers and researchers in regulatory agencies," they recognize that in this group there are not very many managers (that is, people who actually manage land). I see this reflected in the type of questions that you've asked—quite good questions, but they are questions that reflect the bias of the group. I wanted to point that out at the beginning. I do represent a land management group, the Forest Service. We directly manage more land than that comprising France, Belgium, and Switzerland all put together. That's just one of the five sections of the Forest Service who have 0.76 million km<sup>2</sup> (187 million acres) of ownership.

I'm speaking as the Remote Sensing Coordinator for the Forest Service; therefore, I have to look at Landsat somewhat differently than someone in a research situation who is going to use Landsat occasionally, or even operationally. When I make the decision, or recommend that a decision be made in the Forest Service, to go with a Landsat-type program, I'm talking about paying for the satellite. You may not have thought of it in those terms. But, if we start talking in those terms in the Department of Agriculture, we're talking about buying or renting it, or at least a downlink in computer systems. We're talking about megabucks, which is a little bit different. When I say that Landsat is not operational for us, I mean it in those terms because I'm not ready to tell my chief that we should buy the computer system and downlink materials.

A couple of the questions were raised here. Somebody mentioned to me that in my abstract I said, "Before remote sensing—satellite remote sensing—can be operational in the Forest Service, we must change our way of making decisions." By that, I mean that remote sensing applications are meant for broad-based decisions, if we're talking about satellites. The Forest Service is a land-management agency which makes the decisions at the ranger district level. It's a very, very independent group. You know, we're very much detached from the home base, and each ranger is keying in his ranger district. Remote sensing, of course, picks up data—inventories massive areas of land, which gives us a different formula for making decisions. When I make that statement in the abstract, that's what I'm referring to.

As a good case in point, in the Rocky Mountain region of the United States, we have a beetle kill that's going into billions of board feet. It reaches to the entire northern section of the Rocky Mountains. We have a lot of standing dead timber. We're inventorying that standing

dead timber right now, but we have to do it statistically because of the size of the land we're talking about. But where do we place the mills to harvest that dead timber? In other words, we may go from a green cut to a brown cut of standing dead timber. We may shift our entire way of logging in that part of the country to try to salvage those standing dead trees. Where do we put the roads? What's the econometric model that we have to work with? Do we put in highways? Do we put in roads? Do we bring in sawmills? And if so, where do we site those things?

Well, remote sensing can make a contribution to that, but the decisions of that magnitude are not made at the ranger district. If we are indeed going to apply remote sensing for the entire northern Rocky Mountain section of the United States, we're not going to be making the district ranger decisions. Rather, we're probably doing it out of the regional office at Mazola, Montana, or the Washington office of the Timber Management folks. So, that's what I meant when I said we have to change our way of doing things if we are really going to apply remote sensing.

The group that I was in raised the question of application—how do we apply remote sensing? I guess we'd better talk about the definition because people walk around that definition all the time. We get a group together, and we talk abstractly about remote sensing being Landsat; but it's really photo interpretation. So, we say that, at the moment, we have no operational use for Landsat data, but that doesn't mean we don't intend to use it. Because of some of the legislation that affects us, we've got to find a more efficient way to do things. We have to make an assessment of the 6500 m<sup>2</sup> (1.6 billion acres) of the United States on a 5-year recurring basis—5 to 10 years. We simply can't handle that kind of data. We can't inventory that magnitude of data by any way but remote sensing.

We now are using aerial photography so routinely that I don't count most of that as remote sensing. We use remote sensing of 1:80,000 on down to about 1:8000 scale. We fly our forest lands every 5 years in color, color infrared, and black-and-white. I don't consider these to be the remote sensing that I'm concerned with as Coordinator.

With respect to the application of remote sensing, we are investing a tremendous amount of money in cooperation with the National Aeronautics and Space Administration (NASA). We have a project at the Johnson Space Center in which we are trying to develop applications. We're looking to the Landsat computerized data—digital processing—to help us out.

If you have specific questions, I'd be glad to address them.

*RAGAN*

Before we move on, does anyone on the panel have any comments on what Bob has mentioned? Two items stood out. One, that purchase of equipment would be part of the feasibility and this idea of a new approach to decision-making. Are there any comments from right here in this group first?

ANTENUCCI:

Bob pointed out something that state people have used, and that is that traditionally we rely on high-altitude aircraft photography. For the detailed work we do in many cases, it is more appropriate at this time than Landsat. Therefore, Landsat is down the road for many of our applications in which we depend on aircraft photography.

RAGAN:

How about getting that into your files? In other words, this may be a good place to branch into the MAGI (Maryland Automated Geographic Information) System. In your abstract, you talk about a data base for the state of Maryland. How do you digitize aircraft data to get it into your files?

ANTENUCCI:

We do that manually. In the past, we have prepared more traditional land-use maps at a scale of 1:63,500 by using high-altitude photography. We prepared that on nylon materials so that we can make copies readily available to substate jurisdictions and to anybody that actually requires hardcopy material. We then encode that information by hand at this point. We are exploring digitizing the data. Since our system is grid-based, we would then grid it from the polygon file.

RAGAN:

You use a 90-acre cell. Is that any transition down to a smaller cell? A lot of people have criticized it as being not usable because of the 90-acre resolution.

ANTENUCCI:

Well, we use a 90-acre cell. It's our basic component. Two thousand feet on the side is 91.8 acres, and it's a division of the State Coordinate Grid System. So, we're tied into that information.

Rather than go to the smaller cell size initially—we had a limitation of funding availability—for certain critical pieces of information, we chose to encode primary, secondary, and tertiary occurrences within that cell. Therefore, for land-use information and for soil information, we've encoded three levels of detail and two levels for geology.

We have recently experimented with an approximately 4.5-acre grid cell, which is a one-twentieth division of the 90-acre cell. We have used this in three test areas, and we now have a much larger test site in the lower Patuxent area in which we are going to do a cost analysis—an effectiveness analysis—of the small data cell for use by local jurisdictions.



We have used both the 90-acre cell and 4.5-acre cell for local governments. There is a tendency to feel more comfortable with the 4.5-acre cell at that level, but we are also constrained because most available traditional map data is not compatible with that scale, except for soil data. Most of the map material available in Maryland is 1:62,500, which better lends itself to the accuracy of the 90-acre format. Although we are sympathetic to the need for a larger—4.5-acre or somewhat smaller—cell, in many cases, the data are not available without a rather large expenditure of money.

*RAGAN:*

I'm concerned about the idea of purchasing equipment as part of the feasibility—as part of the economics of whether or not remote sensing is applicable. In your paper, you talk a great deal about the Office of Remote Sensing and Environmental Research (ORSER). What do you think of the purchase of equipment? Does this amount to a large economic investment based on the experiments with San Jose, etc., that use ORSER?

*CRESSY:*

A range of investments are required, and there is no single answer. If I were at a transition phase, the only way to accomplish any real integration of the new technology into someone's existing way of doing business is to cause a minimal disruption to the way he does business. That means that you would attempt to make use of equipment that is commonly found in the adopter's offices or laboratory for the way he does business now.

Our experience with San Jose, and with other people, has been that most of the local planning offices have an available typewriter computer terminal that they can use in a dialogue mode to some computer system. For them, this may represent the cheapest possible way to encounter digital data and digital data processing. In many cases, they already have the machinery for the most simple approach. In fact, the most expensive cost to them may be telephone costs in the hookup to the central computer. The availability of national time-share networks may even minimize those costs.

*RAGAN:*

But hasn't San Jose kept records of their telephone bills, etc., between in-state and hours expended?

*CRESSY:*

They sure have. I don't have the final numbers on that. We have basically finished most of our interaction with the planning office there. But for about a 6-month period, their use of the data processing system at Penn State University by telephone hookup amounted to less than \$1000 and much less than \$1000 in Central Processing Unit (CPU) time.

This is for the planning officer in San Jose who has probably exercised every program in the Penn State library, rather than most of the people in our facility at the Goddard Space Flight Center. He has spent perhaps 25 percent of his time during that period working on his programs and on digital data related to the San Jose area. If he had gone commercial, telephone charges would have been extensive. They do have to pay commercial long-distance rates. However, telephone charges through a commercial time-share network would mean that he would be dialing a local call in the San Jose area; in that case, the charges would have been minimal.

That is an almost hypothetical network. The network doesn't really exist yet. No commercial time-share remote sensing analysis is nationally available. But, from our experience with several universities and private companies, we believe that this kind of service is just around the corner.

RAGAN:

Jim Wray, have you used the Automatic Remote Processing Antenna (ARPA) network to do a lot of time-sharing work?

WRAY:

Not counting our use of remote sensing source materials for our national program, but speaking only for our research and development efforts using the Landsat digital data, we are not using any U.S. Geological Survey facility. A small exception is about \$4000 that we spent for a remote computer terminal and about \$3000 for the silent digitizer. These were the only equipment investments. In the past year, we have not spent more than \$15,000 for computer services elsewhere. The computers that we use are on the ARPA network—the Advanced Research Projects network of some major computer facilities across the country tied together by high-speed telephone lines.

In our processing of Landsat data, there are three major computer operations, and we use a different computer setup for each one, choosing what we want to use from the ARPA network for the preprocessing work—the reformatting of the tape to put it into the form required by the software we are using. We use a version of the LARS-III system, now called Editor, developed by the University of Illinois Center for Advanced Computation. In this preprocessing work, they are apt to use a 360-91 from Southern California that makes preliminary geometric corrections and does the reformatting that I referred to and overlaying of scenes if we're using data for more than one time. About 2 years ago, costs were running about \$3000 a frame for these operations. Now, it is down to about one-tenth of that.

The second operation is the interactive one in which the analyst works interactively with the data and sets up classes statistically, using a PDP-10 capability at a private firm in Boston. The PDP-10 has the same software requirement that runs the front end of the Illiac computer—the parallel processing computer based at NASA Ames Research Center and also on the ARPA network. The Illiac is such a formidable number-cruncher that people cannot run it. It takes

a battery of computers to run the computer. What gets you onto the Illiac is the PDP-10 capability which, for the ARPA network, is based in Boston. From a remote terminal at our desk—in this case, in California—we made the tapes. We do not transmit large quantities of data over the telephone line. We mail the tapes or the input data to this facility; however, it operates 24 hours a day, 7 days a week, and we can telephone at any time.

As for the telephone, we are able to use a local tip. We use the computer for a communications device. We do not use the telephone except for local calls to the nearest contact point. There is one contact point at Fort Belvoir, but we have difficulty getting on that one. There is also one at the National Bureau of Standards in Gaithersburg, Maryland. Most of our work is done at the Ames Research Center, California, on a tip there. That is the second computer we're using for the interactive operation.

When our classes have been established, we have another number-crunching path that is done, not on an interactive computer, but in batch mode. For this, we turn to a different computer facility that is also on the ARPA network.

*RAGAN:*

But all operate from one terminal?

*WRAY:*

All operate from one terminal. It can be a suitcase on your desk. For this, we have been using mostly the Illiac-4 located at Ames Research Center. But, from a computer terminal in my office, we might be doing the classification for, say a 7.5-minute quad in Idaho. We have previously sent the tapes and done the preprocessing. The data can be called up from this remote terminal in our office, and the analyst may spend 2 hours setting up the statistical classes for this 7.5-minute quad. The Illiac works so fast that it can only work in batch mode. Therefore, the job is turned over to the Illiac. We may get the answer in 20 minutes or 2 hours or certainly overnight. In the particular case I have in mind, the Illiac assigned the classes to each of about 34,000 pixels for a 7.5-minute quad in less than 2 seconds for \$1.40.

*RAGAN:*

So, this would be something, say, that's down the line for accessibility when Phil Cressey's hypothetical network is set up. That will be integral to this hypothetical.

Jim Manley has used the Penn State network that you will be seeing this afternoon as a regional tool.

*WRAY:*

It is not necessary to use a parallel processing computer for this work. I think the question of what is the best hardware or software to use often comes up, and I think there is no answer

to that question. Many people are working at this in different ways, and the best way to go is with whatever particular combination of help you have, hardware and software. In this case, we just lucked out and happened to have access to this. But a CDC-7600 will do the same job about ten times faster.

*CRESSY:*

I want to add one thought to this, and I noticed a question that appeared on several different charts that I want to respond to as well but just to add to this.

You mentioned a hypothetical system; it isn't quite as hypothetical as you have made it sound. We know, for example, that, with their ORSER system, Penn State has a dialogue environment that is to some modest degree commercially available. They are now in the process of establishing some sort of an arrangement for commercial accounts. The Laboratory for the Application of Remote Sensing (LARS) in Purdue has some kind of commercial availability. They are now tied to a fairly expensive terminal system and card-entry system but are testing and evolving a more easily accessible dialogue approach, the way the Penn State ORSER evolved.

We know that Dames and Moore has purchased the ORSER package and put it on a time-share network for their in-house use, not really realizing that there was an outside user community that would be interested in access and in paying them for the privilege and for their support of that process. We have talked with Dames and Moore and are encouraging them to test the commercial feasibility of supporting that process. We have talked to, and encouraged people from, General Electric Company (GE) and Computer Sciences Corporation (CSC). CSC has put a version on LARS and is having some trouble, or LARS has been having some trouble making it operational.

But there are several approaches to this, and several people have expressed interest in approaching this issue. Perhaps it needs a fair amount of encouragement not only from NASA or the U.S. Geological Survey (USGS) but also from a potential user community. They can begin knocking at doors and say, "We're interested in this possibility. We would like to discuss with you further the potential costs for this capability and the uses for it."

*RAGAN*

We are alluding to the question of how and where does one begin in making use of remote sensing data. It is one of the processes in which we emphasize the digital aspects of it.

*JAMES*

I have a question that maybe I could clarify a little bit. I felt that we were coming here as a group to study the applications of remote sensing to the Chesapeake Bay. This morning, we have talked about a lot of high technology. We've talked about many of the other places

in this 3.5 million square miles we call the United States. We have not spent a fraction of our time worrying about or even considering the 7000 square miles that make up the Bay. If we want to help solve the Bay problems in the time that we have available to us in this conference and come out with anything productive, I think we should talk about the Bay problems—real Bay problems.

There have been many other conferences addressed to the high technology of satellite systems, computer programs, digital analysis, etc., but all of these do not apply directly to the Chesapeake Bay. I think that some of our time should be devoted to more mundane approaches that we really meant to address here—the Chesapeake Bay.

*ANON:*

I had a question along that line. In looking through the abstracts, I noticed that when we talked about remote sensing, most of the people wrote about Landsat's contribution of digital data. But you are dealing with the Bay and raw material, pollution, salinity, etc. I have not heard any mention of data-collection platforms and satellite telemetry, which I think is a major facet of remote sensing. It isn't scanner data, but it is reflecting data remotely. I'm on the Agriculture Remote Sensing User Task Force, and that is one of the areas that we are looking at. We found that the Forest Service collects data from 8000 data-collection stations. Many of these data could be telemetered to the satellite and transmitted to wherever you wanted to bring it back. That is the meteor burst type of things.

It seems to me that, monitoring the water, pollution, etc., of the Chesapeake Bay would lend itself to a solution by the use of data-collection platforms, and I wonder if anyone here has done any work with that.

*RAGAN:*

Dan, do you want to comment very briefly on that?

*ANDERSON:*

Well, that technology is here, and we are moving ahead as fast as we can with our experimentation. We have used the Landsat system. Landsat-C will have the data-relay capability, but Landsat-D will not. Therefore, that will be essentially the end of data-relay systems as far as Landsat is concerned. But the main viable system at the moment is the computer stationary operational environmental satellite operated by the National Oceanic and Atmospheric Administration (NOAA). At the present time, we—the USGS Water Resource Division—have a contract with COMSAT General Corporation, and they are using one of their commercial satellites. Actually, it's a Canadian satellite; they have a frequency on the Canadian satellite. They are in the very beginning of experimenting with this satellite. Depending on how you

classify the systems, we collect data of some type from nearly 50,000 stations. There are probably about 18,000 various kinds of actual recording stations. But it's a very viable system, and we believe that, as time goes along, we will be able to collect better data quicker. In other words, a lot of users really want near real-time data.

ANON:

Is anyone familiar with what can be collected from his data-collection platforms?

ANON:

Commercially, Environmental Research and Technology, Inc. (ERT), started about 10 years ago, and its primary business has been collecting data, primarily research in the Boston area and throughout the United States now.

Bob Bartlett, the chief engineer, has been working with the same satellite contact. One of the things we have looked at is a midstep—a dependency on the real time versus long term data. In other words, do you take an action, or do you take a study observation? Hopefully, we'll get a chance to talk with those who are interested in it this afternoon at 3:30.

The regionalized systems, one of which has gone into two states now, give you the ability to have a hands-on real-time action analysis, and then go off into what I call a batch collection—a satellite collection—trade-off. Of course, it is going directly from the sensors into the satellite and back with the attendant time delays. It is part of the systems design. Generally, it's a mixed bag. The kind of data you can collect would make the two distinctions between hydrology and quality, and there are good sensors in both of those areas. Sometimes you mix the two; sometimes it's one or the other.

RAGAN:

Jim Manley has faced a similar problem in merging an array of data dealing with land use and water quality. He is located on the edge of the Bay. Could you comment on this interface of data, your U-2, your satellite, your photographs, and your water-quality information.

MANLEY:

Until last September, we have been working with U-2 photography to develop land use for the Baltimore area. It has been pretty good. We have then gone into planimetering the areas and have gotten totals by regional planning districts that are aggregations of census tracts, watersheds, etc. We have since gone into a polygon storage system in hope that, when other types of statistical areas come along, we will be able to more easily summarize those.

However, this did not get into the kinds of questions being asked here. They were interested in nonpoint pollution. We turned to Intralab to help us get on Landsat and to give us information on undeveloped areas in the Baltimore region.

We do have a problem, however, in interfacing the grid system from Landsat (approximately 1 acre) to a polygon system. We haven't really gotten all the bugs worked out. We hope to use some computer packages that are available.

*RAGAN:*

Are you actually taking any water-quality data? Are you actually in the streams or in the Bay for water-quality data?

*MANLEY:*

Yes, through the two-way program. I'm not directly involved in that, however. As an aside, GE is working with the city of Baltimore in the Loch Raven Reservoir on the data-collection platform. We are getting some information from that. I'm not involved in that either. I did notice in some of the questions that people were very much concerned in operationalizing the use of Landsat data—how to get on and how to get output back from it. I come from a geography discipline with basically no remote sensing background whatsoever. As of last September, I began working with Intralab using the Penn State ORSER system, and we have developed a pretty good working knowledge. I haven't really run into any language barriers. There have been some minor problems, such as pixels. Documentation certainly is not really available. I've worked some of it myself, and I would certainly hope that we will work on more in the future.

We are definitely in favor of getting a local system at the University of Maryland or someplace else for applications that users have in the Baltimore Washington metropolitan area.

*AXON:*

The variables that we have been transmitting by data processing systems (DPS) are temperature, pH, dissolved oxygen, and specific conductants. There was a time when we evaluated an entire array of variables, and I'm sure there are other variables that could be interfaced into the system for transmission. But, this is what we have transmitted at this point.

*RAGAN:*

We keep coming to the question: how does one get into it? We have talked about the ARPA network; we have talked about ORSER, etc. Frequently there are, I'm sure, organizations that a lot of us represent that are really using remote sensing as a one-shot-only type of thing. We need an answer for one thing, and then we may not need it again for a couple of years or



perhaps 6 months. Consequently, for continuity and completeness, there is still another vehicle for extracting remote sensing information, be it satellite or aircraft. This vehicle is the commercial operation such as that of Bendix, International Imaging System, and the one that Arch Park mentioned very briefly on this mode that General Electric has with their Image-100 system. Therefore, we have ORSER, ARPA, and the Image-100 system, which offer still another input for people like Baltimore County, who just did a study of one of the watersheds that empties into the Bay.

*PARK:*

I think Bob articulated the situation. It is such an expensive machine that the only logical thing is for most of the users to use it as a service. We do offer that service, and there are other companies who do. There is little to choose between them, except for levels of sophistication, usually related to the software associated with the machines. It is characterized by being interactive in its design, and the design will not change in the respect that the user employs his own spatial pattern recognition skills against a scene in an interactive mode. It is therefore an interface between the man and his data in a very special environment. It is not designed to be competitive with any other kind of analytical mode. It serves only that one role—the interactive analytical situation.

*CRESSY:*

For those who are interested, without endorsing GE or anybody else, in the back room where the ORSER demonstration is set up for the afternoon, you will find a display board from GE that gives you an idea of what that system will look like and a couple of other display boards that indicate how that kind of interactive system has been used on various analysis projects.

*RAGAN:*

Could we open this up to the rest of the room because we are getting very specialized on one or two questions. There may be someone back there who has a question that we haven't seen on your board and who wants an answer before he leaves here.

*BOHN:*

I just want to mention, without endorsing the system you use, that several videotapes will be shown tonight that actually show how it operates.

*PARK:*

I should make my own position clear. I am a user of Image-100. The GE Space Division does not build them, it does not sell them, and I am sometimes its most vocal critic. The



Ground Systems Division builds and sells them. We badmouth it occasionally ourselves. So, feel free.

*RAGAN:*

I mentioned it because of the way that I came into it, knowing nothing about remote sensing other than that I needed some parameters defined. It's a mode by which there is a trained operator on the system, and you work with him rather than trying to know everything yourself, because I didn't go back for another 6 months. It wasn't because I was mad at the machine. I had my data, and I didn't need any more data. And so, that's an aspect.

Does anyone else have a question that we haven't got to and that is important to you?

*HILL:*

I have a question. Landsat could be used for several different things, but, with the Governor's Conference coming up, NASA is getting to the point, I believe, at which they are asking people to pay for this kind of thing. When the Governor's Conference decides on the problems, we have a list for working-group topics—boat densities, oil spills, point sources of pollution, water quality, chlorophyll, turbidity, etc.

Landsat is designed for land. All we've talked about is land use. Who are the suppliers? Where do you go to get historical imagery? From talking around, I believe that NASA cannot provide U-2 imagery all the time. Where is this higher resolution? I'm not crossing off Landsat, but, from our topics, perhaps Landsat could be used for 30 or 40 percent of our work. Certainly, there is a large percentage that we cannot use it for, and I haven't seen that brought out.

*RAGAN:*

Source of data—anybody care to comment on that?

*BROWN:*

NOAA has done excellent U-2 photography for configuration of shore lines, harbor, etc.

*HILL:*

I understand the U-2 is an extremely hard thing to get hold of.

*CRESSY:*

Can I address that for just a second? There is existing U-2 data that NASA has acquired that is available from the USGS Earth Resources Observation System (EROS) Data Center in

Sioux Falls. This is the commercial source of this information, along with various other kinds of NASA-flown aircraft data. It is certainly true that, in the foreseeable future, NASA's collection of aircraft data will dwindle away. I don't want to say to the vanishing point. I'm sure that NASA will still be flying aircraft in support of experimental sensors, etc. But NASA is trying to get itself out of even any appearance of competition with commercial sources of aircraft imagery. The commercial capabilities in the area of aircraft imagery have been increasing greatly in recent years. There are now commercial sources for very high altitude and 50,000-foot type of aerial imagery. Therefore, you will find that, for up-to-date U-2-type aircraft imagery, you will have fewer and fewer opportunities to find that kind of data because less and less data of that sort is actually being acquired.

*RAGAN:*

Well, your question was repository and historical data—historical imagery. John, in your agency, is there a repository of historical imagery?

*ANTENUCCI:*

We've made an attempt to keep on hand all the high altitude data that has been flown by NASA since 1969. Now, we also try to keep up to date, although not very successfully, the holdings of low-altitude aircraft photography by other state agencies. We have a listing that is probably up to date as of 1975 or 1976.

*ANDERSON:*

I was going to say something about the National Cartographic Information Center (NCIC) that operated under the USGS. They have acquired aircraft data from all other agencies, including the Forest Service. The United States is divided into the five parts, and there will be still another one for Alaska and Hawaii. These data are related to 7.5-minute quadrangles, and are identified by the symbol of the agency that has collected that data. But those data are available. Perhaps you know more about it than I do, Jim. There are the types of data, and, if you take a look at them, you will see how the data are divided and how the symbols are installed. That would be one part. That is No. 5 there, isn't it?

*WRAY:*

Region 5. There are publications like this matched with the United States—a machine print-out by 7.5-minute quad—and printed in each quad is the numerical symbol giving some information about who holds the information, its date, and percentage of cloud cover. This is the latest one out, and these indexes are for any part of the country. Five sets of them are available from the NCIC. There is a sale price on these. I have one example here. You are all

invited to look at it and then go to NCIC for answers to your questions. It's cataloged—the photography holdings at EDC and many other agencies. There is a brochure on the back table that described NCIC and a few other parts of the survey and federal agencies where you can get this kind of information.

*RAGAN:*

You can type out coordinates to obtain the listing of everything, and you can order things like 1947 flights, 1950 flights, etc. You get a little mosaic about 18 inches square, and you can pick the plates you want out of it. It's not very expensive.

*CRESSY:*

I think that Wallops Flight Center on the Eastern Shore also has some historical data of the Chesapeake Bay region from various aircraft support missions that they have flown in this area over the last decade.

*ANDERSON:*

I had a couple of questions. One involved accuracy of resolution requirements for users. I think some of us are a little uncomfortable about discussing Landsat and some of its applicability specifically for this reason. We seem to be talking about some of these rather sophisticated systems such as those of General Electric and Bendix as if they were operational. I think we have to understand that much of this is still in the research mode as far as applying it to specific problems. For instance, I'm not sure that anyone has addressed accuracy for much of the land-use work that has been done and applicability to specific kinds of problems that we have in the Chesapeake Bay area.

The other question that I think we had in our group was the problem of interface (that is, the ultimate problem of educating and passing on sensing technology to the user. We've been asking this question since 1968. It is a question we ask every time we get together—how do we do it? They're doing a little better now than in the past, but it still continues to be a problem. One of the things that I think has occurred over the last few years has been the rise of consulting firms to fill a gap between what has been basically a research effort in the federal government and an applied effort that really wasn't available to the user. Some of us are really concerned that, in some areas at least, there is competition between federal agencies and private corporations for funding projects. How much and how far should the federal government be involved in some of these projects, and at what point in time should they be turned over to corporations that are in the business to pass on this technology and to actually provide a usable product for the individual or for the user or they go out of business. Should the government be involved to a certain level only? I think a lot of us are concerned with that. Where one ends, where the other begins, and where the funds go in this type of thing?

*RAGAN:*

John Stewart?

*STEWART:*

The Park and Planning Commission of Montgomery County has a computer mapping system, and we have applied it to a lot of things in our work, particularly with the location of sanitary landfills and different types of urbanization and optimization for different types of land use. Our cell is 4.5 acres, and we've encoded a number of factors for Montgomery County; we found it quite useful as a practical tool.

*RAGAN:*

Ken, you were getting into another phase of remote sensing that we haven't touched on, because we tend to get to talking about exotic approaches and things and we think only of satellites. But that isn't going to answer all the problems. And Ken has another problem in remote sensing—the remote sensing of underground structures. Would you comment on some of your views on the problems of the Bay and how this thing is tending to start out at the end of this first session.

*WEAVER:*

Before I do that, I'd like to bring up one general thing. One of the questions I see is, "Are we finding too many answers to questions that we really haven't asked yet?"

I think that's part of our problem with the entire Landsat program. There are a lot of answers there, but what are the questions?

Also, there is another point I'd like to bring out on a philosophical level, and that is, "Are we really overselling the capability?" I don't mean among ourselves. I mean to people that don't really understand the types of things that remote sensing can do for you—legislators for instance.

I'm sure that there are some legislators who think that Landsat has a mapping capability and therefore you don't have to go out and do geologic mapping or we don't have soil mapping, etc. I think that is a communications problem that we have to consider. As Bob said, geologists have been interested in remote sensing for many years. We didn't call it that, but that's what it is—seismic information, for instance. There have been literally hundreds of thousands, if not millions, of miles of seismic lines run on the Continental Shelves off the United States for very specific economic application—oil and gas. As an analogy between that and Landsat, there wasn't a push to run 50,000 seismic lines across the United States to get subsurface geologic information. That would have been nice for us geologists, but I don't think it could have been sold. But I think that would be an analogy, between that particular type of remote sensing capability and Landsat.

There are other types of remote sensing, such as aeromagnetics—the State of Maryland is now covered with aeromagnetics—that are very helpful tools for interpreting subsurface geology. I think we look at Landsat in the profession as a tool and only as a tool. It will do some things for us. Some real junk has been published in the literature, for instance, about lineaments on Landsat images. That is great to see a line on a Landsat image and say, “Yes, by definition, that’s a lineament,” but what does it mean? Is it actually a natural feature? Is it a geologic feature, etc?

There are also some “gee whiz” type of things. We have been a principal investigator in Landsat-1, and you can look at the image of the Bay area, and, sure enough, you can see the South Mountain anticlynorium in the upper left-hand corner, showing up very beautifully because of the land-use patterns, geology dictating what the land-use pattern has been. However, we have known that for years. That was mapped in the early 1900’s as a geologic structure.

But I think the more practical thing was what we entered into with NASA in mapping the strip-mining area and using computer-compatible tapes. There is a very logical application for those data, and I think Anderson did a fine job on that.

*RAGAN:*

This is probably a good place to finish up this session. We have gone full circle. I guess I started out at first trying to hammer that we must be able to interface with multifaceted remote sensing devices. There’s no single sensor that will give us our answer. We’ve gone through a lot of discussion that was centered heavily on Landsat, and probably correctly so. But we also have to consider Ken’s urging that we are talking about more than one sensor. So, let’s not let our conference center only on one sensor.

*MILLER:*

I’m from the State of Maryland Energy and Coastal Zone Administration. I have two immediate needs that have direct-landing implications, and I’m looking forward to my funding for next year, setting aside monies to do some of these tests the conventional way. One of them has to do with prevention of significant airshed degradation. One of the pollutants targeted there is  $\text{SO}_2$ —a very heavy effort funded by the Environmental Protection Agency (EPA) to look for sulphur emissions in the midwest and how the transport and transformation of sulphur affects things in the flight path. From some of the earlier calculations that were done, Maryland looks like it’s directly in that flight path, and it’s a synoptic type of study. We are not talking about resolutions of a meter; we are talking about resolutions of a kilometer. I believe that remote sensing is ideally suited to this. The implications of this type of work are vast. It could mean that you have to take things like major power sources, put them in a plum pudding type of model, and spread them out uniformly, or you might want to concentrate them in some way—give them some kind of regulatory mandate to do it.

These are immediate questions, they are before Congress. There are things on the books within EPA and within the state that are going to have far-reaching expensive consequences in the state.

Another point that pertains to the Bay is to look at pH and long-term pH trends as seen in the Scandinavian countries. Maybe we don't have quite that kind of problem.

The other one is the photochemical oxidant problem. The whole northeastern corridor looks like it's shaping up to be a noncompliance area in EPA parlance. And that means, since you are not meeting the regulations, people have to get tough with the emitters to put the lid on emissions. One proposal is to draw a circle, an 80-mile radius, around major cities like Baltimore and Washington and say, "No major emitters." The major emitters aren't awfully large in some cases (for example, the major emitters of hydrocarbons). We're talking about ozone; we're talking about hydrocarbons. Put these two packages together and it means that we have to be very careful about putting any sort of major development near a city; and the converse of that, which is one significant airshed degradation, means that we have to keep the clean air even cleaner.

Now, this is for real, and we have to get information on this. I'd like to be approached either privately or in any other way by people that have ongoing programs that might help in this way.

#### PEMBERTON

Perhaps you'd want to draw up an open session for Thursday or Friday. We are a little bit. Let's continue the discussion over lunch. Thank you all.

#### Addendum

The following questions were listed on newsprint by the working groups after the opening three 20-minute presentations. The asterisked questions were not considered by the Session 2 panel. This is not to say that all other questions were "answered," but that they were considered during the discussion.

#### CRESSY

##### 1.\* Intralab

- Relationship to subcenters (e.g., AEC)
- Willingness to establish technical and financial support

\* Question not discussed by Session 2 Panel.

2. Clearinghouse
  - Data sets
  - Physical models
  - Techniques/applications?
3. Intralab—Who should/is/will be the focus for an integrated study of the Bay?
4. Remote sensing techniques for water quality—Where can the technician get the answers?

HICKMAN

- 5.\* Alternate R/S data when Landsat is out of phase with a "real life situation"?
  - Oil spill
  - Algae bloom
6. USGS Advancements in mapping with Landsat—What is the comparative accuracy versus traditional sources?
7. Resolution Level—Does it pose problems to the users?

CRESSY  
WRAY

- 8.\* Accuracy of classifications
9. Where are we going in remote sensing?
  - Courses/seminars
  - Technology improvements—resolution new sensors (thermal)
  - Demonstration projects
10. How to get into the action phase (out of the R&D phase)? Should "Government" be a part of the action phase?

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\* Questions not discussed by Session 2 Panel.

11. Where are costs paid for?
  - Direct to user
  - General funds
  - Can we make a profit making venture for commercial firms?
12. Are we finding too many answers for questions that haven't be asked?
13. Missing Users—Why?
  - National Marine Fisheries
  - Interior—Parks and Recreation
  - Congressional Aides (Policy Formulators)
  - Commercial Users (Weyerhaeuser/Rochester and Pittsburgh Coal Co.)
- 14.\* What new regulations might be developed in the future?
- 15.\* Is "Agriculture" the same in USGS/EPA?
16. Clarify statement on economics of R/S.
17. Change in technology level will dictate change in decision making? (Clarify.)
18. User's Guide—How do you transfer technology to the field? Clarify training mechanism.
- 19.\* Why not combine Great Lakes and Chesapeake Bay?
20. Identify potential users and users' needs.

WRAY  
KOUTSANDREAS

CRESSY

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\* Questions not discussed by Session 2 Panel.



CRESSY  
MOON

- 21.\* Court litigation—Acceptance of Landsat data?
  - Interchange of expertise between NASA labs.
  - Are all NASA capabilities to be included?
22. How to get the right kind of material to user—Negative reaction to poorly selected example
23. Can costs be reduced to expand user applications?

ANTENNUCCI

24. Surface water quality information—what kind?
  - Water aquifers?\*
  - Detail of land use—cell size?
  - Who is in charge of historical data on Bay?
  - Compilation of remote sensing information on Chesapeake Bay region?
25. What have we learned from experience about the technology transfer problem?
26. What can be done to overcome “language” barriers? To improve understanding of remote sensing as a tool?

MANLEY

- 27.\* Should we consider as “user community” those who act on information only, or include those affected by such actions?

WEAVER

- 28.\* Is the 100- by 100-mile Landsat scene restrictive?
29. How can remote sensing data be presented effectively persuasively visually?
30. What are the implications of the approved Landsat-C, -D, and -D’ systems?
31. Is there a consistency or fragmenting of direction of technology use among NASA, USGS, private firms, etc.?

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\* Questions not discussed by Session 2 Panel.

- WEAVER
- 32.\* If a detailed map is prepared using a statistically acceptable sampling technique (i.e., Landsat = community level A/C = species composition) will it stand up in court?
33. How does one establish a hierarchy of driving mechanisms for developments in remote sensing? Do we not need to look at specific problems and look towards analyzation techniques and deal with problems?
34. Regional application transfer—Maryland first state: Who (what professions) will be involved in planning R. A. T.?
- JAMES
- 35.\* How does EPA interface with NASA to provide for coherent global monitoring?
36. Are we putting all the eggs in one basket with Landsat?
- ANTENNUCCI
- 37.\* What is appropriate cell size for statewide planning level? County feedback on Maryland size?
38. Applications of remote sensing
39. Interface between government and industry for remote sensing applications?
- WILKERSON  
MANLEY
- 40.\* How/where does one start making use of R/S data, such as by a Citizens' Group?
41. Who is working on the process of converting R/S data to information usable at the local level?
42. How do we evaluate who the potential users of R/S data really are?
- BRUN  
CRESSY  
JAMES  
WRAY
- 43.\* How much "ground truth" is needed to exploit R/S data?

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\* Questions not discussed by Session 2 Panel.

- WINSTEAD            44.\*   How do we justify expenditures for research and development as to use of R/S data for prospective program application?
- BRUN  
WINSTEAD            45.\*   What would be the role and authority of a proposed Chesapeake Bay Commission versus, say, Coastal Zone Commission, EPA, etc.?
46.   To what extent do local agencies want to process R/S data for their own use, or to receive help from other groups?

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\* Questions not discussed by Session 2 Panel.

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**SESSION 3**

**RESOURCES OF THE BAY REGION**

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## INTRODUCTION

G. Daniel Hickman

*Inland Environmental Laboratory*

*University of Maryland*

*College Park, Maryland*

The main theme of this session was the necessity to treat the Chesapeake Bay as a "complete" system. Only by so doing will people be able to realize the full resource potential of the Bay. Remote sensing provides us with the necessary tools that make it possible to obtain extensive synoptic coverage of the Bay. Such coverage provides us with time-history, which, without remote sensing, is not possible.

This section includes excellent reviews on state-of-the-art remote sensors that are operated from boats, aircraft, and satellites. It is obvious that emphasis should be placed on how to optimally use the data from the sensors that are currently operational and those that are scheduled for flight on the new line of satellites (Seasat, Landsat C and -D, and Nimbus-G), which are to be placed in operation during the next few years. The most important single area of concern is the Bay eutrophication. The general consensus is that, in this area, remote sensing can be extremely valuable. Some of the sensors to be flown on the new satellites have been especially designed to have spectral bands that are optimized for water penetration studies.

A new "remote sensing" tool that is now available to the Bay community is the physical hydraulic model of the Chesapeake Bay located at Kent Island. A real challenge exists for Bay scientists and managers to "tie-in" the capability of this facility for understanding Bay problems with remote sensing techniques using boats, aircraft, and satellites. In other words, how can the physical model guide remote sensing experiments, the results of which, when fed back into the physical model, yield a better understanding of the total Bay system.

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## ON MEASURING THE STATE OF THE BAY

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### INTRODUCTION

One way to ascertain the state of the Chesapeake Bay is to ask others how they think it is doing. The answers might be as follows.\*

#### State resource management officials

- The Bay is essentially healthy. There has been no illness since the 1930's that is traceable to contaminated shellfish. In 4 years, the acreage closed by sanitary pollution for shellfish harvesting has fallen from 134 to 24 km<sup>2</sup> (33,000 to 6000 acres). What problems we see today are probably an aftermath of Hurricane Agnes, which dumped an enormous volume of pollutants and freshwater into the Bay. The Bay is resilient and will recover.
- The average Bay oyster contains 20 parts per billion (ppb) of chlordane, 2 ppb dieldrin, 20 ppb of polychlorinated biphenyls (PCB's)—levels that are almost nonexistent for people who eat these shellfish.

#### Some political figures

- The Bay is much cleaner today than it was 20 years ago.
- No seafood product has had pollution problems, and I haven't heard of anyone who went swimming in the Bay getting sick.
- The Bay is reasonably clean.

#### An author

- "The watermen . . . think the real problem is something harder to pinpoint. As they go out year after year the water seems to be changing. It may be, they think, that it is everywhere getting a little tired. Each summer there are more fish kills and in winter you can sometimes see strange little red dots suspended in the water. Old, tired and a little messy, you could even say. Age is coming to the Bay, too perhaps. Simple as that." (Warner, 1976).

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\* Some of these responses are essentially verbatim; others are paraphrased. Several are taken from a recent series of newspaper articles (Franklin and Burton, 1977).

**An editorial cartoonist**

- One cartoonist (Flannery, 1976) depicted the state of the Bay in the drawing shown in figure 1.

**Two watermen**

- I can remember when the water was clear, when the Bay actually sparkled. Today the waters are littered with the filth being thrown out.
- Everything will come back. The fish, oysters, crabs, and clams. They always have and will continue to do so.

**A charter-boat operator**

- The Bay is in pretty good shape, and so are its fishes. Out-of-state parties can't believe how good our bluefishing is. (But his sportsfishing was off by one-third not because of kepone, he feels, but because of a kepone scare.)

**A biological photographer**

- Like the cartoonist, his opinion is stated in images. Figures 2 through 4 are essentially aesthetic and moralistic statements about the beauty of the Bay, its productivity, and the adverse effects of some human activities.

**A State fisheries biologist**

- Every species that spawns in the Bay is experiencing recruitment failure—oysters, striped bass, shad, white perch, and others.

**Two university biologists**

- The Bay oyster you eat is not being replaced by nature. Something is killing the young, and every year there will be fewer adults to harvest unless something is done.
- The Bay is overfertilized. We see chlorophyll blooms in winter as dense as the blooms we used to see in midsummer.

And so it goes—contradiction and confusion. However, the statements share certain common characteristics: All of them are intensely subjective, none can be fully separated from the speaker, and all are expressed with deep conviction.

Clearly, there should be a way to characterize the state of the Bay that does not depend on the individual and the particular measure he chooses. What is needed is a general measure of the Bay ecosystem—one that will define its status and reveal the effects of changing uses and demands. As Ellerman (1968) put it, "The Bay is more than a body of water. It is a



Figure 1. Editorial cartoon, *Baltimore Sun*, September 30, 1976  
(printed with permission of *the Baltimore Sun*).



Figure 2. Typical Bay scene, photographed by M. J. Reber,  
Chesapeake Biological Laboratory, Center for Environmental and  
Estuarine Studies.





Figure 3. Plankton sample from 1/2 M Net. oblique tow, 5 minutes, surface to 4.6-meter (15-foot) depth. Includes larval fish and barnacle nauplii, zoea of blue crabs and mud crabs, and various copepod species, photographed by M. J. Reber.



Figure 4. Baltimore Harbor outfall, photographed by M.J. Reber

source of food and livelihood, a biological dwelling place, and a road to the sea. It is a place of constant change, and it has so many faces and such a variety of moods that it develops its own distinct personality. Clearly, the Chesapeake Bay is a complex thing, and if we proposed to improve it, we should understand it as completely as we can."

The Bay is a unified system. A system is defined as any methodical arrangement of parts which has collective characteristics distinct from those of its constituents by virtue of interactions among them. A painting, for example, is a system; so is an orchestra.

The human being is a system and is sometimes used as an analogy. Although all of his elements (cells) are replaced during a lifetime, the identity of the individual human is preserved. His most highly integrated collective property is his subjective consciousness, or perhaps his soul. This property is virtually impossible to measure. If our task were to characterize the collective *physical* state of a human being, however, the answer would be easy: periodic physical checkups with more elaborate diagnostic tests if something unusual turned up. Routine data would consist of measurements such as body weight, heartbeat, blood pressure, and temperature.\*

Determining the collective properties of the Bay is much harder, partly because the Bay is so much larger and in some ways more complex, and partly because no one really agrees what the collective properties are. In other words, we are proposing to measure without knowing exactly what it is we want to measure.

### EXAMPLES OF BAY DATA

Let us examine some examples of the kind of data that have been recorded in the past. Figure 5 shows 30 years of data on the Maryland oyster harvest. Although the graph has its ups and downs, it shows no particularly disturbing trends. However, figure 6 shows a sobering downtrend in the production of *new* oysters that, if unchecked, must inexorably reduce the harvest. A downtrend that has run its full course is shown in figure 7, which portrays a 9-year decline in Maryland shadfish recruitment that is mirrored later by a virtual disappearance in the adult population. Figure 8 shows similar data for striped bass, which show a less conspicuous trend or perhaps none at all.

Data come in many forms. The foregoing examples are measures of populations of Bay animals, and they can be taken to constitute one definition of the status of the Bay. A different kind of data record was compiled recently in an effort to systematize historical Bay data retrieved from fourteen sources. A total of 358,000 observations at 4381 sites was tabulated for the years 1939 through 1974. Eight water-quality variables were included: temperature, salinity, dissolved oxygen, pH, alkalinity, opacity, suspended solids, and chlorophyll  $\bar{a}$ . Still

\* Note that the doctor does not cover your entire body with thermometers and transducers to measure body temperature and blood pressure; these are obtained at one point only and are inferred elsewhere. This is not the case for the corresponding measurements of the Bay.

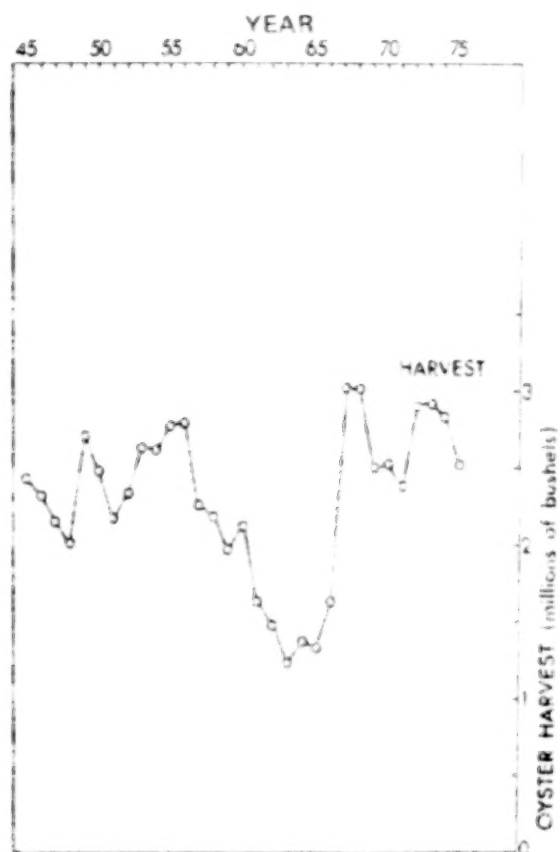


Figure 5. Harvest of oysters from the Maryland portion of the Chesapeake Bay in millions of bushels per year; 1945-1975 (Meritt, 1977).

another kind of data record is a survey of the presence or absence of submerged aquatic grasses compiled throughout the Maryland Bay for the past 6 years.

If these examples seem to lack a common theme, I have made my point. Although Bay data have been gathered at great cost over many years, there is no coherence to the totality of the measurements. Undoubtedly, this situation results from the fact that measurements have been associated with specific purposes—biological experiments, hydrographic studies, or species surveys—rather than with the system as a whole.

### VITAL STATISTICS OF THE BAY

I have heard Maryland described as two land masses separated by a large body of water and connected both spiritually and physically by Cecil County only. Some essential geographic features of the Bay estuary, including its tributaries, are its length (about 320 km—200 mi), width (8 to 48 km—5 to 30 mi), area (11,400 km<sup>2</sup>—4400 mi<sup>2</sup>), mean depth (6.4 m—21 feet),

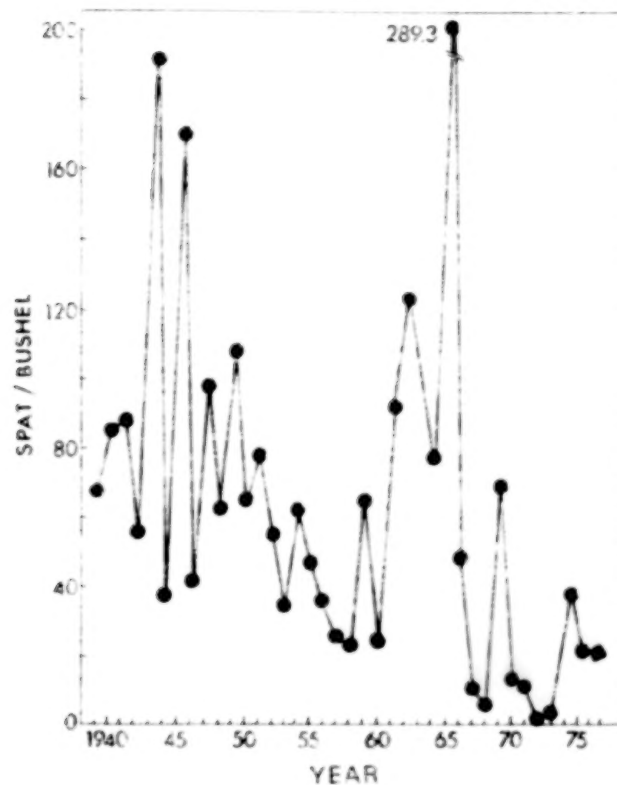


Figure 6. Spat production on natural cultch for Maryland portion of Chesapeake Bay, 1939-1976 (Meritt, 1977). Point for 1977 was obtained from unpublished data.

perimeter (13,000 km-8100 mi), and volume at low tide (76 trillion liters-20 trillion gallons or 12 mi<sup>3</sup>). It drains a region encompassing 191,600 km<sup>2</sup> (Lippson, 1973).

The Bay sustains an enormous economic enterprise. In 1973, the Maryland commercial fishery, predominantly the Bay system, produced 31.8 million kilograms (70 million pounds) with a direct dockside value of 24 million dollars (Maryland Statistical Abstract, 1975). The total economic impact of water-based recreation in Maryland, primarily Bay related, was estimated at 221 million dollars for 1970. In 1974, 37 million metric tons (41 million tons) of cargo valued at 7.1 billion dollars\* were shipped into and out of the Port of Baltimore. The direct impact of the Port on Maryland's economy has been quoted at 600 million dollars with a total (direct plus indirect) impact of 1.56 billion dollars, providing more than 62,000 jobs (Maryland Department of State Planning, 1972). The Bay is indeed a major factor in the lives of citizens who live around it.

\* To sustain shipping channels, the U.S. Army Corps of Engineers annually dredges more than one million cubic meters of material in 120 projects.

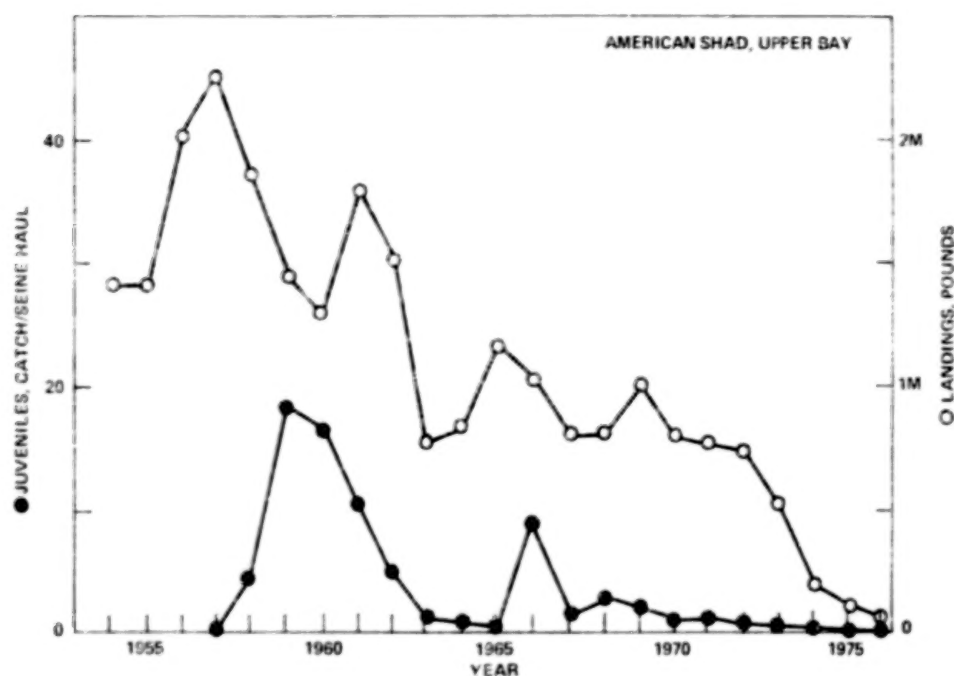


Figure 7. Shadfish recruitment and harvest for Maryland  
(from Maryland Fisheries Administration).

## REQUIREMENTS FOR A BAY INFORMATION SYSTEM

For the balance of this paper, I would like to address three questions:

- What entities should be measured in a comprehensive data base?
- How close together should measurements be made in space and time?
- What should be done with the data?

Although I am not knowledgeable enough to answer these questions (neither is anyone else), I feel that the following characteristics are essential to a proper information system:

- To be useful with existing scientific knowledge, the entities to be chronicled must include at least those items that have been measured and computed in the past—simply because they are the basis of an entire scientific literature, as well as regulations, standards, and laws. Thus some items that will surely be included are: temperature, salinity, dissolved oxygen, pH, turbidity, chlorophyll, alkalinity, suspended solids, current-vector field, ambient light, abundance of adult and juvenile stages of various species, trace toxins, nutrients, oxygen demand, and indicator bacteria.\*

\* In attempting to impart structure to this list, the reader might find it helpful to classify items according to the dogma of systems ecology as either "state variables" or "parameters." The latter are identified as those factors (like light level, temperature, or salinity) whose values are independent of the state of the system. Almost everything else is a state variable. This is not exactly the same as distinguishing cause from effect because some state variables (say, turbidity) can be both an effect and a cause.

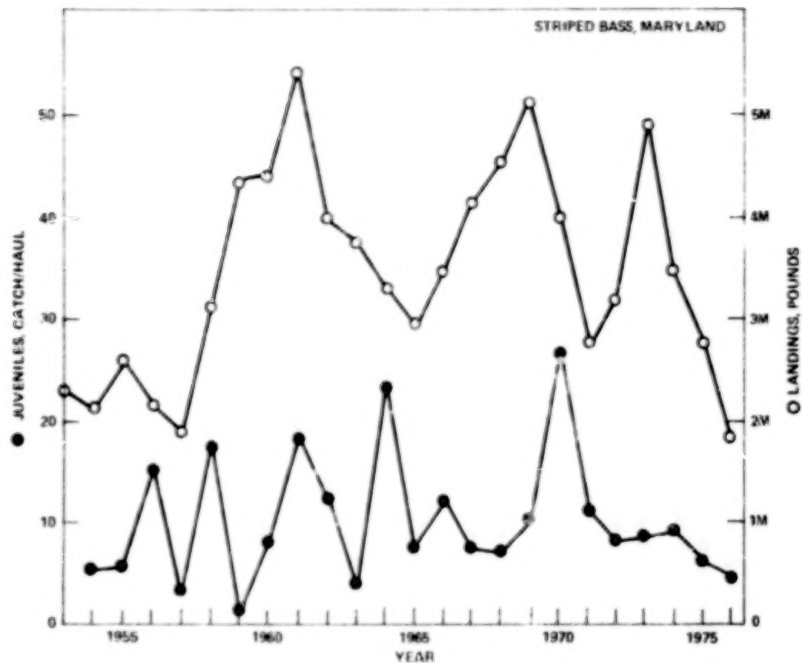


Figure 8. Striped-bass recruitment and harvest in Maryland (from Maryland Fisheries Administration, National Marine Fisheries Service, and Maryland Power Plant Siting Program).

- The data must be compatible with an index or set of indexes that gives a running numerical record of the overall condition of the Bay. The notion of collective numerical measures used to describe the state of a system is familiar in meteorology; it is the weather report. The National Wildlife Federation compiles an index of natural resources (National Wildlife Magazine, 1977). The Overseas Development Council has devised a physical quality-of-life index (Sewell, 1977). However, the Canadian environmental quality index (Inhaber, 1974) is perhaps the closest analog. Although there is no guarantee that an environmental quality index—perhaps to be called a “Bay condition index”—will ever be developed, such a construction is not unlikely, and it does impose requirements on the Bay data base that make sense on their own merit. The requirements are:
  - Data should be numerical rather than descriptive.
  - Data should be normalizable to a standard value set by a regulatory standard, a health standard, or some other measure of a threshold between acceptable and unacceptable (normal versus abnormal) levels.
  - Data should be as universally understandable and applicable as possible.
  - Different items of data should cover the same time periods so as to reveal any correlations between measured values of variables that may be inter-related.

- Data should be capable of expansion or revision as dictated by improvement in data gathering technology or understanding of the ecosystem without loss of prior information.
- Data should be credible. This implies two conditions: both the measurement techniques, including validation and calibration procedures, and the error limits or uncertainties in data values should be entered as part of the data record.
- The spatial scale and temporal frequency must satisfy several criteria.

Both "global" and local spatial grids are necessary. Baywide scales are needed to discern Baywide trends and patterns; and fine-grained spatial arrays are needed to reveal specific imprints of manmade or natural singularities, such as a sewage-plant effluent pipe or a river mouth.

Any spatial array of measurement points should be tailored to the spatial gradients in the quantity being measured. With salinity or temperature, for example, horizontal sampling points can be as far apart as a circulation model or an established empirical intersite correlation permits interpolation; but vertical sample points must be spaced closely enough to profile the thermocline or halocline that occurs with two-layer flow.

- Similarly, time sequences should be fitted to the characteristic times for changes in the variables of interest. By definition, an annual recruitment survey is done once a year (preferably at the same time every year), but a turbidity measurement protocol might employ a variable time scale in which the sampling rate is stepped up when the turbidity starts to change suddenly, as after a heavy rain, and is slowed the rest of the time.

Although these considerations seem self-evident, they do not appear to have been put into action as a practical matter. An illustrative example is the simple measurement of temperature. A thermometer can be dropped overboard, and the temperature recorded daily or even continuously.

- 1 The data display is then a very long list of numbers or an analog recording of temperature,  $T$ , versus time. We keep such a record at two of our laboratories. A more compact data base might give the mean temperature at noon each day or of the daily high and low, averaged over a historical period of many years and perhaps augmented by mean square deviation in  $T$ . But an even more efficient representation is possible when only the average temperature is needed. Ritchie and Genys (1975) have

shown that the average daily temperature at one point in the Bay can be modeled with uncanny accuracy by a fourth-degree polynomial:

$$T = \sum_{n=0}^4 a_n d^n$$

where  $d$  is the day of the year. A plot is given in figure 9. Thus if it is sufficient to know only the average temperature, an entire table of data can be reduced to five numbers. To my knowledge, however, no one is keeping such a set of numbers for the entire Bay.

Another illustrative example involves sampling a living population of, for example, a fish species. If the fish are known to distribute themselves more or less at random, then a uniformly spaced sampling grid may be appropriate. But, if the fish are known to school, paired or multiple sampling, in which the decision to take successive samples is conditional on a "hit" with the first sample, should clearly be more efficient. The situation is not unlike a game of "battleship."

- Data gathering methods should exploit improvements in technology. Although most living populations are sampled by dropping nets or other gear overboard, acoustic sampling should be superior in principle. Active optical devices should be entirely feasible for plankton sampling *in situ* and for size discrimination. Remote sensing should offer a tremendous advantage with any quantity for which an optical signature exists and a two-dimensional representation is adequate.

Although I am not very familiar with the methods used in aquatic sampling, what I have seen appears superficially to be primitive. Techniques used in routine practice appear to lag far behind what is technologically feasible. The underlying reason may be the unwillingness of any economic sector to subsidize the cost of developing new devices and measurement techniques.

- Costs must be held down. Time in the field is expensive. Anyone who is not familiar with aquatic field work may not appreciate just how expensive it is. The cost of data acquisition is the dominant factor in the design of most of our field studies. Thus, every effort must be expended to establish minimal data needs. The cost of overspecification is great if it results in excessive boat time or related costs. Furthermore, time and money should not be spent on recording variables known to be closely and predictably correlated.
- After a data base has been designed and created, it must be used. There is a tendency for newcomers to the Bay (like me) to assume the existence of a rich untapped heritage of data just waiting for the resource manager or ecologist to exploit. This



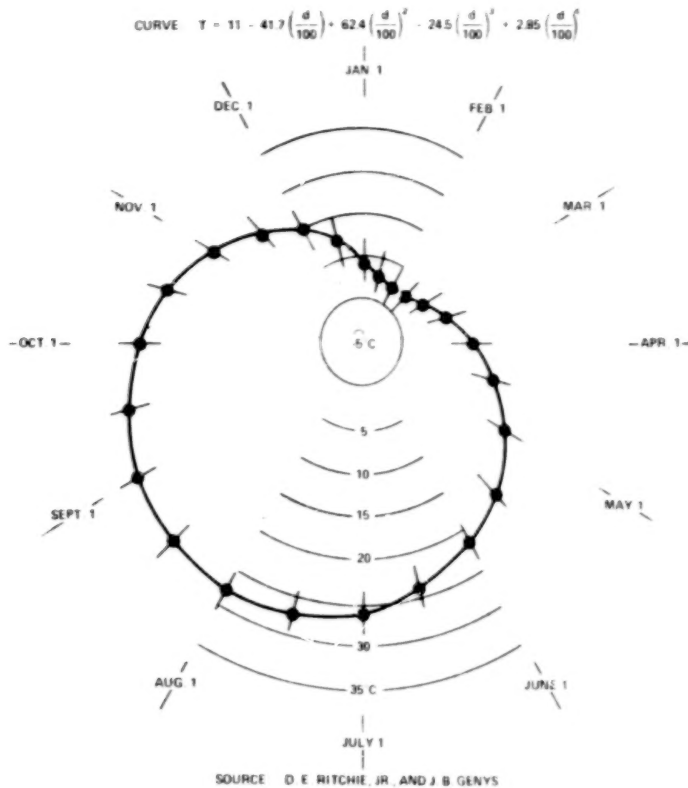


Figure 9. Temperature at 1.2-meter (4-foot) depth at Solomons, Maryland, 1938-1967. Bars show highest and lowest values over 30 years (Ritchie and Genys, 1975).

is not the case. Although the water quality data base mentioned earlier is a most useful compilation, I heard two scientists complain about its inadequacy within the last month. Bay scientists and managers are not used to having a centralized collection of data available to them because there never has been one. When the Chesapeake Bay data base is brought into existence, strong coercive measures, such as requiring its use as a condition of awarding grants or approving new regulations, should be invoked.

- The data program must contain built-in provisions to register extreme values. The importance of "alarm systems" has been eloquently stated elsewhere (Lee, in Kelly, 1976): "Water quality is often determined by extreme values, not averages. It is generally related to the effect of certain constituents in the water on one or more beneficial uses. For many beneficial uses, especially those related to a healthy ecosystem, there may be just one or two short-term events each year which determine overall water quality for the entire period. For example, it is not average trace-metal concentration which is toxic to benthic organisms, but extremes. A pulse during

the course of one evening can completely devastate a population. Under these circumstances there would be no relationship between parameters measured for a trace metal over an annual cycle and the presence or absence of a particular group of organisms. Similarly, with respect to eutrophication, it is not generally average numbers of algae to which the public responds. It is the extreme events associated with a bloom, such as piling up of *Cladophora* on the shore, or tastes and odors in drinking water, that register."

I have heard it conjectured that the Bay is governed less by the average behavior of the driving parameters than by extreme events—hurricanes, high rainfall, dry spells, and cold winters. Although this speculation may or may not be correct, it should be taken into account.

### DESIGN OF A MONITORING PROGRAM

Having laid out the foregoing requirements, I would like to conclude by suggesting a plan for the actual design of a comprehensive data system.

One way would be to be guided entirely by that blend of intuition and experience we call insight or "enlightened common sense." This approach does not appear promising because the task is too complicated and too demanding of thorough analysis. Nor do I feel that the existing Bay scientific community can do the job alone because this segment is relatively ignorant of the data requirements of user groups.

Another approach might be to construct a theoretical model of the ecosystem and let its data requirements be accepted as the right prescription. Such a model has been developed for the Delaware Bay (Kelly, 1976), and the data required for input and model verification are clearly indicated by the descriptive article.\* But ecological systems theory is a young and largely untested science; it does not seem prudent to guide one underdeveloped methodology with another.

To me, a sensible approach is the one followed by the Canadian government (Inhaber, 1974) in developing its environmental quality index. A working group would be assembled from the two principal factions involved with Chesapeake Bay information: (1) those who gather and study information, primarily scientists and agency field personnel, and (2) those who need information, chiefly governmental officials but also personnel in industry, recreation, and commerce.

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\* Input quantities include physical characteristics of the estuary (dimensions and water flow from all sources), influx of BOD, N, P, and O (by treatment-plant outfalls, industry, tributaries, and storm-water runoff), input of heat, suspended solids and toxic materials, and light intensity. Calculated variables include the N, P, and C in algae, fish, and zooplankton, which should be measured to verify the model.

This group would meet in a series of intensive planning sessions with the specific goal of answering the foregoing questions: What should be measured? How close together should the measurements be in space and time? How should the data be handled?

I would suggest that the group proceed by analyzing several actual Chesapeake Bay phenomena on a case-by-case basis to learn what kind of historical data would have been desirable for a working understanding of each phenomenon if these data had been on hand when the event occurred.

I nominate the following case studies for consideration:

- The steep decline and partial recovery in abundance of submerged aquatic grasses
- The recruitment failure of Bay-spawning species
- The effect of the unusually cold winter of 1976-1977 on fish, shellfish, and crabs
- The peculiar mortality patterns of benthic species in the Chester River
- The apparent eutrophication of the Bay
- Kepone in the James River
- The effects of very high pulsed freshwater flow from the Susquehanna River, such that caused by Hurricane Agnes and spring "freshets."

If these are not enough, past occurrences or hypothetical events of a plausible nature can be invoked. Eventually, the exercise will end when the data requirements for any new case are found to be already listed. I suspect this closure will occur rather quickly.

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## USE OF REMOTE SENSING TECHNOLOGY PROVIDED BY THE NASA/WFC CHESAPEAKE BAY ECOLOGICAL PROGRAM

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### ABSTRACT

Use of remote sensing technology provided through the NASA/Wallops Chesapeake Bay Ecological Program was investigated by means of extensive interviews with users. Since the inception of the Program 4 years ago, the technology has been used in 136 different managerial projects. Sixty-five regional managerial agencies took part in projects that the authors categorized as socioeconomic, political/managerial, monetary, legal, and other. Remote sensing technology was considered successful in 88.6 percent of the completed projects and unsuccessful in 2.8 percent.

### INTRODUCTION

The National Aeronautics and Space Administration (NASA) is enfranchised to conduct research and development programs in aeronautics, space exploration, and related disciplines. Its policy and obligation is to apply the fruits of its work to the benefit of the public (Park, 1972). Under NASA auspices, remote sensing has matured into a tool of practical application. NASA's role in the maturation process imposes upon the agency the responsibility for transferring the technology and methodology into the civilian domain. With outside advisement, NASA has undertaken to accomplish the transferral by cooperative projects with major civilian management agencies and academic and research institutions (Remote Sensing Handbook, 1975).

In 1971, a remote sensing program—the NASA/Wallops Flight Center (WFC) Chesapeake Bay Ecological Program—directed by Paul Alfonsi was initiated to further implement the process of transferring remote sensing technology into the public sector. The Program is intended to serve as a pilot study in the use of practical applications of remote sensing for problems of concern to regional managers. To achieve its goals, the Program acts as a catalyst in bringing resources managers and scientists together and in supplying aerospace tools to solve ecologically oriented problems.

The present study evolved out of an investigation of the previous year that was designed to identify ecological problem areas and to compile an inventory of interested and potential users of remote sensing data (Ulanowicz, 1974). The objectives of the present study, conducted 5 years after initiation of the Chesapeake Bay Ecological Program, are: (1) to provide a solid overall assessment of the Program; (2) to determine all management agencies and participants who utilized the data; and (3) to determine uses and implications of the data.

## PROCEDURE

The method employed in the present study was to conduct personal interviews with all agencies and persons using remote sensing technology provided through the Chesapeake Bay Ecological Program. Interviews were prearranged and preceded by a written questionnaire, were normally restricted to 1 hour's duration, and were conducted with the aim of obtaining any and all information from the users that would reveal the character, extent, and success of the use of the NASA material.

## RESULTS

Sixty-five user groups used imagery from the NASA/WFC from 1971 to 1975. Of these, 24 users initially contacted WFC and requested the information; these users are designated "primary users" in the study. An additional 41 user groups that cooperated with the primary users in projects are designated "cooperative users." Cooperative use of the imagery was common, with a number of agencies interacting repeatedly in using the imagery in various projects. The primary users were:

- U.S. Geological Survey
- National Park Service
- U.S. Fish and Wildlife Service
- U.S. Army Corps Engineers
- Maryland Department of State Planning
- Maryland Water Resources Administration
- Maryland Geological Survey
- Maryland Forest Service
- Maryland Bureau of Mines
- Maryland Department of Chesapeake Bay Affairs
- Virginia Division of Forestry - Insect Disease Investigations
- Virginia Institute of Marine Science
- Accomack/Norhampton (Virginia) Planning District Commission
- Chester County (Pennsylvania) Board of Health
- The Nature Conservancy
- Pennsylvania State University
- University of Delaware - College of Marine Studies
- University of Washington - Department of Anthropology

Virginia Polytechnic Institute and State University

University of Massachusetts—Cooperative Park Studies Unit and Coastal Research

University of Virginia—Department for Environmental Science

University of Maryland—Center for Environmental and Estuarine Studies

Rudolph Baliko—Forestry Consultant

Ecology and Environment, Inc.

Table 1 shows the relationship of primary to cooperative users.

Table 1  
Primary Versus Cooperative User Status

Agency Category	Primary Only	Cooperative	Cooperative Only	Both
Federal	0	17	13	4
State	4	13	8	5
University and College	3	10	6	4
County	2	5	3	0
Private	2	12	11	1
Total	11	55	41	14

Utilization by the various users was found to involve a wide range of applications (categorized in table 2), including environmental, socioeconomic, political/managerial, monetary, legal, and other subdivisions. Primary users among federal, state, and county agencies exhibited emphasis on planning for public use of natural resources, defining environmental boundaries, and regulating and monitoring activities that affect the environment.

Table 2  
Major Emphasis of Users and Projects

	Utilization of Emphasis					
	Environmental	Socioeconomic	Political/Managerial	Monetary	Legal	Other
Primary users <sup>1</sup>	22	16	5	9	7	8
Projects <sup>2</sup>	23	14	6	6	13	15

<sup>1</sup>Primary users totaled 25. Because the above table categorizes projects in which users were intensively involved, a given user may be listed in more than one of the categories.

<sup>2</sup>Projects totaled 136. Because the above table categorizes projects by their major emphasis, each project appears only once. Two projects that were in multiple categories are listed.



A full listing of projects that involve the NASA/WFC imagery is too lengthy for inclusion here. At the time of the report, 70 of the 124 projects had been completed, 51 were in progress, and 13 were in the planning stage. Projects included regional managerial efforts such as the preparation of a land-use plan for Maryland, conducted by the Maryland Department of State Planning; environmental assessment such as the preparation of wetlands maps, conducted by the Maryland Water Resources Administration; law enforcement efforts such as the prosecution of dredging and filling permits violators, conducted by the U.S. Fish and Wildlife Service; and studies of circulation patterns in the Delaware Bay, conducted by the College of Marine Studies, University of Delaware. For a full listing of projects and a discussion of regional and management-oriented projects, see Fuller et al. (1976 and 1977).

To facilitate analysis and to identify the character, the area of interest of each project was identified. The highest percentage of projects (47 percent) emphasized political/managerial aspects, followed in descending order by environmental (17 percent), other (11.9 percent), socioeconomic (10.4 percent), legal (8.4 percent), and monetary (4.5 percent). Many projects had one or more areas of emphasis in addition to the primary area of interest. The environmental category was involved in the largest number of projects (122), followed in descending order by political/managerial (114), socioeconomic (95), other (71), monetary (54), and legal (37). The major emphasis of projects is shown in table 2.

The emphasis categories listed in table 2 are defined as follows:

- Environmental—pertaining to the condition, protection, and improvement of man's terrestrial, aquatic, and atmospheric surroundings.
- Socioeconomic—affecting the cultural activities, health, and general welfare of the citizenry.
- Political/managerial—referring to the managerial and administrative responsibilities of public officials and agencies.
- Monetary—pertaining to the financial effects on government, private enterprise, and individual citizens.
- Legal—pertaining to the formulation of laws and regulations and the detection and prosecution of violators.
- Other—the dissemination of NASA remote sensing data in the form of publications, maps, graphics, etc.

To underscore major management categories, the projects were also classified from a regional managerial viewpoint. Eight managerial categories were defined in the analysis: land use, public health and pollution, fisheries and wildlife, agriculture and forestry, wetlands and coastal plains, geomorphic studies, archeological or miscellaneous, and resource inventories. Percentages of projects in each managerial category and representative sample projects for each category are shown in table 3. The high percentage of projects in the wetlands and

Table 3  
Managerial Classification of Projects

Percent	Major Project	Representative Sample Projects
15.4	Land use	Inventory and review of Maryland surplus land
12.5	Public health and pollution	Mosquito ditching projects
1.5	Fisheries and wild-life	Malaise in wild waterfowl attributable to water pollution
12.5	Agriculture and forestry	Agricultural land inventory
42.6	Wetlands and coastal plains	Migration of Tangier Island
3.7	Geomorphic studies	Investigations of the geomorphic forms known as Carolina Bays
3.7	Archeological or miscellaneous	Location and evaluation of archeological sites in Maryland Coastal Zone
8.1	Resource inventories	Evaluation and inventory of Maryland mineral, soil, and water resources

coastal category (42.6 percent) is noteworthy. Three additional categories, land use, public health and pollution, and agriculture and forestry constituted an additional 40.4 percent of the projects.

Assessments of the success of remote sensing technology in achieving the desired goals of given projects were made only on the 70 projects that were completed. Sixty-two projects (88.6 percent) were rated fully successful, six (8.5 percent) were rated moderately successful, and two (2.8 percent) were rated unsuccessful.

Sixteen projects that exhibited obvious dollar values were included in preliminary analysis to determine the monetary impact of the Chesapeake Bay Ecological Program on the region. In the present study, the authors sought only to derive an influence rating for remote sensing as applied to various industries affected by remote sensing. The influence of NASA/WFC remote sensing technology was considered heavy in six projects, intermediate in seven projects, and light in three projects. The monetary value of the influenced industries exceeded 15 billion dollars. The authors recommended further studies to assess the monetary role of NASA/WFC remote sensing.

The aspect of remote sensing cost-effectiveness was examined for 20 projects that exhibited clear monetary implications. The costs and effectiveness of alternate methods and remote sensing were compared in each of the projects. The users were questioned about alternate methods as follows:

- What would the comparative costs be?
- What would the comparative effectiveness be?

In more than 50 percent of the projects, alternate methods were rated less than equally effective, and, in 30 percent of the projects, alternate methods were considered ineffective. In 20 percent of the projects, the alternate methods were assessed as prohibitive cost-wise, as well as ineffective in results. In none of the projects was the alternate method assessed as less costly, and in only one was it considered more effective. In 20 percent of the projects, the alternate method was assessed as equal in effectiveness, but at a "much greater" cost. In an additional 20 percent, the alternate method was assessed as "equal in effectiveness" at "greater" cost, and in one project (5 percent), the alternate method was assessed as equal in cost and in effectiveness. The analysis was therefore favorable to the use of remote sensing in the projects examined.

User testimony was evaluated to determine the degree to which users did or did not favor the use of remote sensing technology in conducting projects for which its use was feasible. User comments solicited in interviews were recorded anonymously in the study's report. Testimony was highly favorable to the use of remote sensing. Thirty-six comments were rated favorable, sixteen comments were rated neutral, and seven were rated unfavorable.

## SUMMARY AND CONCLUSIONS

In the course of the study, the authors conversed with dozens of persons representing a wide range of regional agencies involved in affairs relating to the environment. As an outgrowth of user interviews and subsequent analysis of the information obtained, the authors developed the following conclusions:

- That the NASA/WFC remote sensing program has reached a substantial portion of the regional management agencies and is involved in the region's most important management projects
- That the management of the region has been enhanced by the NASA/WFC program
- That remote sensing technology is cost-effective
- That NASA/WFC has made wise and effective use of the remote sensing resource in its charge in the selection of primary cooperators

The authors recommended:

- That the Chesapeake Bay Ecological Program be given additional support and emphasis
- That a better interface be established to coordinate user needs with the NASA/WFC remote sensing activities
- That an instructional program in remote sensing be created as part of the Chesapeake Bay Ecological Program
- That research and development of new remote sensing technology proceed vigorously and be accompanied by the stimulation of utilization of existing knowledge
- That all equipment and facilities of the Chesapeake Bay Ecological Program be updated to bring the Program's capabilities closer to the state of the art.

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## HYDRAULIC MODEL OF THE CHESAPEAKE BAY

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The Chesapeake Bay, like nearly all estuaries, is a complex hydrodynamic system. It is acted upon by a variety of meteorological, hydrological, and physical forces in a way that is not completely understood. Because of this, both the solutions to present problems and the planning for future use involve rather complicated analyses—analyses that are beyond our capability to achieve unless we have available to us sophisticated analytical tools that reduce the Bay to an understandable and manageable scale. Such a tool is the hydraulic model of Chesapeake Bay.

The use of models in studying hydraulic problems is by no means a new concept. It is an evolutionary outgrowth of over three centuries of applied and theoretical engineering studies. It is known that some early hydraulic investigators assembled rudimentary models that simulated natural phenomena. Then, as now, many of the flow conditions encountered in estuarine areas were not subject to rigorous mathematical analyses. It was not until 1875, however, that the French engineer, Farque, applied hydraulic modeling techniques to solve a problem from actual engineering practice. The second attempt to use a hydraulic model for an operating problem took place in England in 1875 when Professor Osborne Reynolds built a model to study the interaction between shoaling and the construction of controversial training works on the Mersey River Estuary near Liverpool, England. Because of Reynolds' study, the proposed works on the Mersey Estuary were extensively revised. Reynolds also called attention to the fact that hydraulic models had potential for use in pollution studies.

Since the time of Reynolds, the types of studies performed with estuarine models have been continuously expanding. In the past 40 years, many important techniques have been developed that have made these tools more versatile and reliable. Of primary value has been the realization that the density phenomenon plays an important role in estuarine processes. This led to the introduction of saltwater into the models and the use of thin metal strips cast into the concrete bottom as a means of providing artificial resistance to the flow of water. The refinement of these techniques by the Corps of Engineers Waterways Experiment Station at Vicksburg, Mississippi, eventually fulfilled Reynolds' prediction regarding the use of hydraulic models for pollution studies.

Today, hydraulic models are larger and more sophisticated than those used by the early pioneers. Their use requires complete integration of many scientific and engineering skills, including those of the hydraulic engineer, hydrologist, oceanographer, and field surveyor.

This is particularly true of the 300-km<sup>2</sup> (117-sq) Chesapeake Bay model—the largest estuarine model in the world. As shown in Figure 1, the model encompasses the Bay proper, all of its tributaries up to the head of tidal effect, and the adjacent overbank areas to an elevation of 6.1 meters (20 feet) above mean sea level.



Figure 1. Approximate extent of the hydraulic model of Chesapeake Bay.

A hydraulic model is a precise measurement of the world, must be protected from all potential sources of disturbance such as vandalism. To accomplish this, the bay model is housed in a 57-km<sup>2</sup> (14-acre) preserve on the western shore of the bay (figure 2).



Figure 2. Aerial view of the shelter for the hydraulic model of Chesapeake Bay, approximately 57 km<sup>2</sup> (14 acres) under roof.

Figure 3 is a diagram of the interior of the shelter, showing its relationship to the hydraulic model and to its appurtenances. The facilities shown comprise an interdependent integrated system in which all components must function properly in order to achieve successful model operation. This system includes:

- Two wells that tap a deep ground-water aquifer to furnish water to the model.
- A water-treatment plant to reduce iron and other minerals contained in the ground water to acceptable levels. The treatment plant is large enough to serve a community of 10,000 persons.
- An elevated reservoir to store treated water for model, domestic, and fire fighting purposes.
- Freshwater inflow devices to simulate the discharge of riverine tributaries into Chesapeake Bay.
- A lixator—a tank in which clear water is mixed with salt and stored until needed.
- An elevated water-supply sump that stores and provides the saltwater required for generating a model flood tide in the headbay and, consequently, the model ocean.



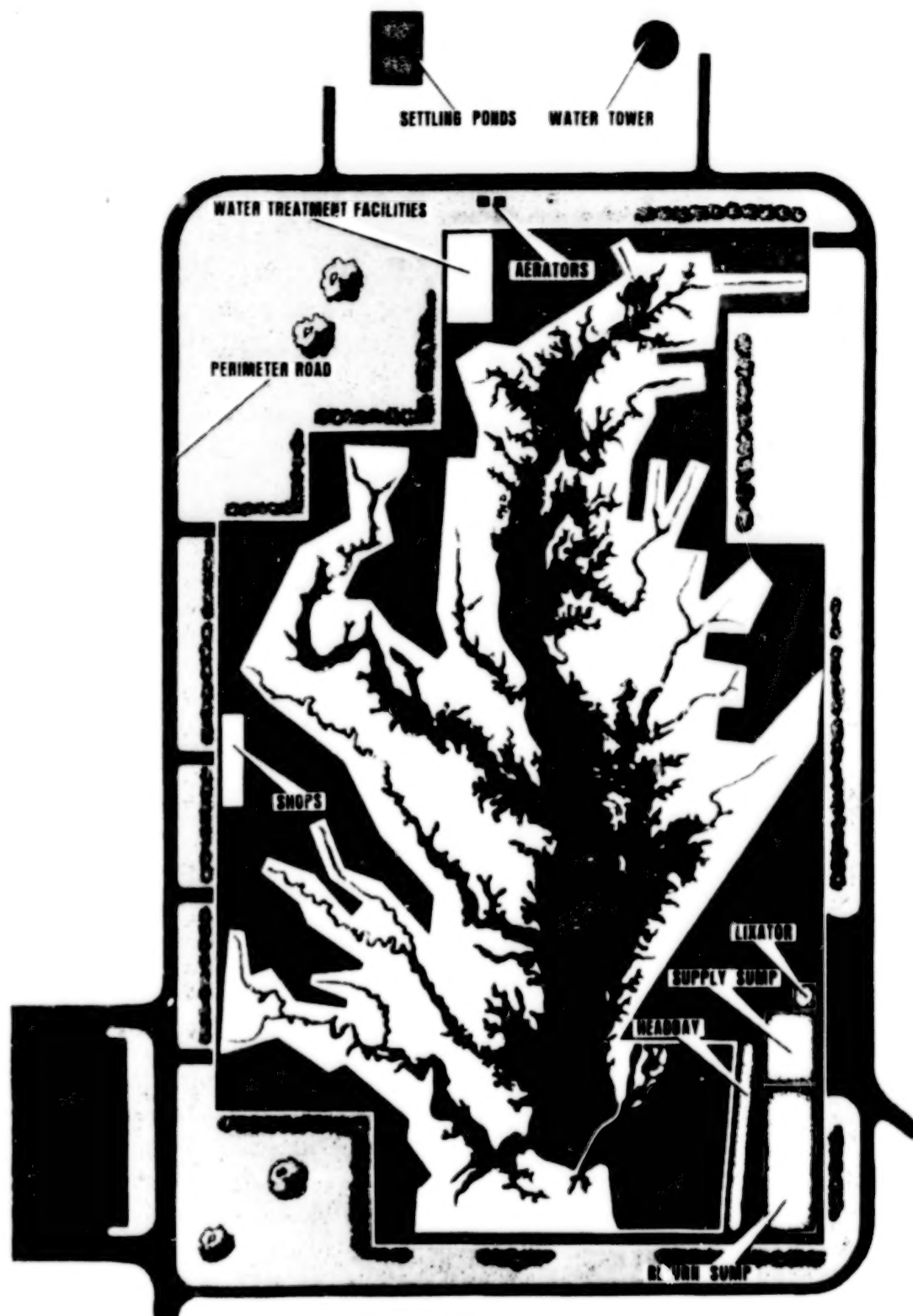


Figure 3. Schematic diagram of the layout of the hydraulic model and its appurtenances in the shelter.

- A degraded saltwater return sump to which saltwater is returned as the model tide ebbs. In this sump, the salinity level of the returned water is adjusted. The saltwater is then pumped into the elevated water-supply sump for reuse.
- A digital control unit that monitors and adjusts the tidal elevations in the model to ensure an accurate reproduction of the prototype. This device also operates the valves that control the flow of freshwater into the model through its tributaries.

The Chesapeake Bay is a typical coastal-plain estuary and is considered by many to be the drowned river valley of the Susquehanna River. The general consensus is that it was formed about 10,000 years ago when the last great glaciers melted, raising the ocean levels to a point at which they covered the river up to about the fall line. The result was a large 322-km (200-mi) long saucer-shaped water body averaging about 76 to 85 meters (25 to 28 feet) in depth. To model such a body of water at an undistorted (natural) scale would be a very expensive undertaking. Through many years of experience, it has been determined that a vertical scale of 1 to 100 is the minimum that provides sufficient depths for meaningful data measurements and that is free of surface tension effects. On the other hand, a model built to a horizontal scale of 1 to 100 would cover an area of over 3642 km<sup>2</sup> (900 acres). To overcome these problems, the Chesapeake Bay model, like almost all estuary models, is geometrically distorted—constructed disproportionally with a larger vertical scale than horizontal scale.

The selected scales for the hydraulic model of the Chesapeake Bay are 1 to 1000 horizontally and 1 to 100 vertically. This combination of scales is known as a distortion ratio of 10 and is considered to be the minimum that will permit an accurate reproduction of the vertical and lateral distribution of current velocity, salinity, temperature, and tidal elevation.

The geometric scales of the model determine the relationship of the model to the prototype in terms of other important parameters. For instance, a velocity of 3 meters per second (10 feet per second) in the prototype would be reproduced at 0.3 meter per second (1 foot per second) in the model, and salinity would be in a 1 to 1 relationship. Most important is the time scale, which is 1 to 100. This means that a 12-hour and 25-minute tidal cycle can be reproduced on the model in approximately 7.5 minutes or 1 year in 3.65 days.

Like all models, the hydraulic model of the Chesapeake Bay must be adjusted and calibrated to ensure that it accurately reproduces the prototype (Chesapeake Bay). To assist in this, an intensive 4-year prototype data-collection program was accomplished. Figure 4 is a map showing the location of stations at which prototype tidal elevations, current-velocity, and salinity data were collected. Tidal elevations were measured for a period of at least 1 year at 72 strategic locations established by the National Ocean Survey. Twelve of these stations were monitored continuously over the entire 4-year period. The National Ocean Survey also conducted a 1609-km (1000-mile) first-order survey to establish a common reference datum for the tidal stations.

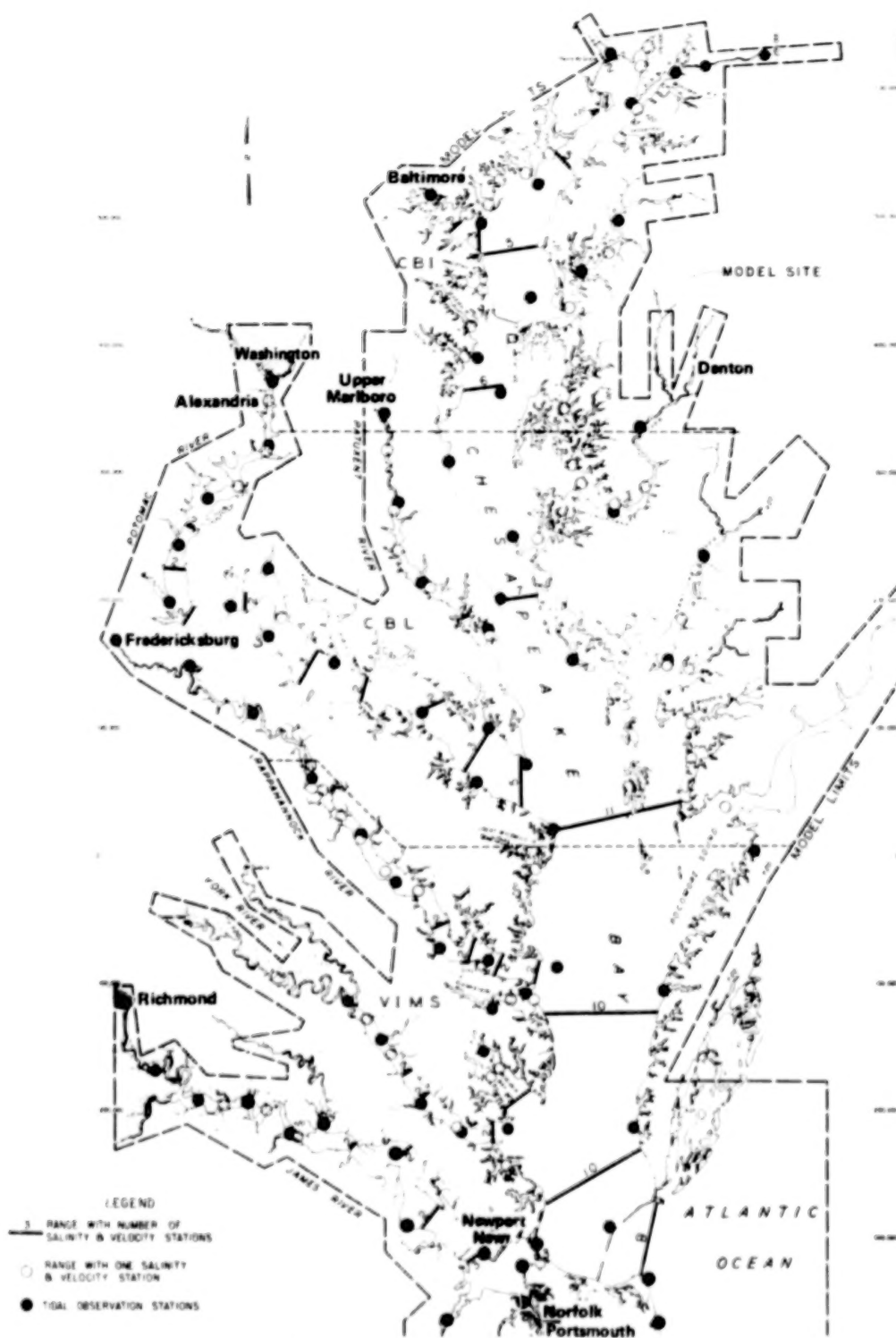


Figure 4. Location field data stations that gather prototype data for adjustment and verification of the model.

A total of 105 ranges were established at various locations throughout the Bay for collecting current-velocity and salinity data. The number of points on each range varied from 1 to 11, meaning that there were a total of 192 locations in the horizontal plane. The number of vertical positions at each location varied from 1 to 12, depending on the water depth, making a total of over 700 observation points at which salinity levels and current velocity were measured for periods of approximately 3 to 5 days. This work was done by the Johns Hopkins University, the University of Maryland, and the Virginia Institute of Marine Science.

Collecting data from a vast body of water such as the Chesapeake Bay is a major undertaking that is complicated by factors related to both the estuary and financial constraints. One of the most perplexing problems of data collection is a function of an estuary's intense biological productivity. An instrument left unattended for even short periods can become encrusted with marine life to such an extent that it may become inoperable. Also, wind, waves, ice, and sometimes even a passing ship can dislodge an instrument from its moorings, causing either lost or erroneous data. In fact, an aircraft carrier did carry a string of instruments over 8 km (5 miles) while work was being done in the Lower Bay. Obviously, an instrument cannot be left unattended for very long periods under these conditions.

The manner in which data are collected also has an influence on the need to have men and boats out in the water. The instruments used for current-velocity and tidal-elevation data in the Chesapeake Bay Hydraulic Model Program had self-contained devices that recorded the data on either film or tape. Salinity data were gathered by various methods, and each method required the presence of a person to either collect or monitor the collection of a sample. Of course, this job could have been easier if sufficient monies had been available for developing and installing automatic nonfouling instruments and telemetry equipment to transmit data to a central monitoring point.

But, the real problem in data collection is associated with the sheer magnitude and complexity of the Chesapeake Bay. Under optimum conditions, data should be collected simultaneously throughout the system at numerous, closely spaced stations. However, this cannot be accomplished with presently available data-collection techniques. There just isn't enough money available to purchase or rent the many boats that would be needed, to purchase the hundreds of meters that would be required, and to pay the salaries of the army of people who would be involved. Rather, data must be collected sequentially consistent with the realistic availability of people, boats, and equipment. In effect, data are collected "piecemeal," and, in the case of the data program associated with the Bay model, over 3 years elapsed between the time the first and last data were taken. One of the real challenges to those involved in research associated with remote sensing techniques is the development of an accurate, inexpensive method of collecting tidal-elevation, current-velocity, and salinity data that would provide for simultaneous data recordings over an extended period of time at many stations spread over large areas.

As previously mentioned, the prototype data are being used in the adjustment, calibration, and verification of the hydraulic model of Chesapeake Bay. This process is both time-consuming and tedious. It is also of great importance because the validity of a hydraulic model investigation is totally dependent on the ability of the model to reproduce prototype hydraulic phenomena within reasonable limits of accuracy.

Because of the previously mentioned scale distortion, slopes in the model are 10 times those in the Bay, making the model hydraulically more efficient than the prototype. To compensate for this, additional roughness is being installed in the form of metal strips that extend from the surface of the model through the water mass. Without this additional flow resistance, the hydraulic model could not reproduce the lateral and vertical distribution of current velocity and salinity.

Briefly, adjustment and verification work is accomplished in two phases—a hydraulic verification that establishes that tidal elevations and current velocities are in reasonable agreement with the prototype and a salinity verification that ensures that salinity conditions in the model reflect those of the prototype.

Initially, using freshwater, a specified tide is generated in the model ocean. At the same time, appropriately scaled freshwater inflows are reproduced in all model tributaries. Model roughness strips are progressively adjusted by hand until prototype tidal elevations and discharges are acceptably reproduced throughout the model within the time phases in which they occur. The next step in the process consists of operating the model with saltwater and further refining the model roughness distribution to achieve an accurate reproduction of lateral and vertical current distribution. The final step involves proper adjustment of both ocean salinity and the location and quantity of freshwater inflows to establish the longitudinal, lateral, and vertical distribution of salinity in all parts of the model.

The foregoing description of model verification procedures for the hydraulic model of Chesapeake Bay is necessarily brief and represents the basic hydraulic and salinity verification. Depending on the studies to be done, further verifications may be necessary. These include a shoaling verification that ensures acceptable reproduction of prototype shoaling characteristics, dye-dispersion verification for waste-water dispersion studies, and storm-surge verification for storm-surge type tests.

Figure 5 shows the hydraulic model of Chesapeake Bay. Models like this have been used for many years in the study of physical processes in the marine environment. They are extremely useful tools in studies leading to a better understanding of the complex estuarine phenomena as well as providing a technique for predicting the effects on a specific water body of both structural and geometric change. As such, they are an important tool for both planning and designing works in the estuary. Through their use, it is possible to evaluate a number of alternative problem solutions rapidly and economically. To obtain maximum benefits from these studies, however, it is necessary to employ skilled hydraulic engineers who are thoroughly familiar with both the uses and the limitations of the models involved.



Figure 5. View of the completed model.

The six basic parameters measured on estuarine models are water-surface elevation, salinity, current-velocity, dye concentration from dye-dispersion studies, temperature, and sediment distribution (considered a qualitative measure). These parameters can describe the physical effect of the works of man on an estuarine water body. In turn, biological stress can often be predicted from the knowledge of changing physical parameters. A partial listing of the types of problems addressed during studies on other models at the U.S. Army Engineers Waterways Experiment Station include:

- Investigations of the changes in water-surface elevations, current velocities, salinity distribution, flushing rates, and waste-dispersion characteristics caused by the geometrical modification of an estuarine water body resulting from the construction of facilities such as navigation channels and port facilities
- Studies of the distribution of sediment as it affects the alignment and maintenance costs of navigation channels
- Investigation of the hydraulics of storm surges and the planning and design of protective works
- Dispersion characteristics and the area of influence of waste-water discharges, including heated discharges of power-plant cooling water



- Studies concerning the feasibility of using the upper portions of estuaries as sources of municipal and industrial water supplies
- Investigations of the effect on estuarine salinity regimes caused by upstream modification of freshwater inflows resulting from the construction of reservoirs or increased consumptive losses because of intensive industrial development
- Provision of basic data for the adjustment and verification of other models, both physical and analytical

**Preliminary planning for the formulation of the first year of hydraulic studies on the Chesapeake Bay model has recently been completed. The primary purpose of this initial effort is to develop a study program that is both responsive to problems of immediate importance and at the same time ensure that from the very beginning of operation maximum economical use is made of the model. The formulation of this preliminary study plan involved an extensive analysis of the environmental, economic, and social aspects of a series of current problems in order to establish a priority listing of their importance. The study program that evolved is oriented towards the analysis of the effects of some of the works of man on the Chesapeake Bay estuarine environment. Included in the first year's work will be:**

- **The Low Freshwater Inflow Study.** This investigation is designed to study the effects on the salinity regime of the Chesapeake Bay System of significantly decreased freshwater inflows because of drought conditions combined with increased consumptive losses resulting from out-of-basin diversions and additional municipal, industrial, and agricultural water uses.
- **The Baltimore Harbor Study.** This work will be undertaken to define the effects on the estuarine system of increasing the depth of Baltimore Harbor navigation channels to 15 meters (50 feet). Parameters to be investigated include rates of harbor flushing, waste-dispersion patterns, salinity distribution, and disposal of dredged material.
- **The Potomac River Estuary Water Supply and Waste-Water Dispersion Study.** This study will explore the ramifications of using the Potomac River Estuary as a supplemental source of water supply for Washington, D.C. One of the concerns generated by using the estuary as a source of water supply is the possibility of recycling waste water into the public water supply during periods of low freshwater inflow and the possibility of changing the salinity levels and current patterns in the estuary.

**The hydraulic study program is scheduled to begin in the fall of 1977 and will be completed within 1 year. Although the presently authorized Chesapeake Bay study has funding sufficient for only a 1-year program of hydraulic investigations, it is anticipated that, with both future funding and expanded use, the Chesapeake Bay Model will have a long productive life and will play an increasingly important role in future investigations concerning the formulation of rational plans of development for the Bay system.**

## ACKNOWLEDGMENT

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## LANDSAT SENSORS

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### LANDSAT-1 AND -2 SENSORS

Landsat-1, launched in July 1972, and Landsat-2, launched in January 1975, are equipped with a similar complement of sensors. Each spacecraft has both a return-beam vidicon (RBV) camera system and a multispectral scanner (MSS) for acquiring high-resolution multispectral data of the Earth's surface on a global basis. These imaging systems, the primary sensors on the Landsat-1 and -2 spacecraft, are described in the following paragraphs.

### RBV SYSTEM

On Landsat-1 and -2, three cameras are used to take pictures of Earth scenes simultaneously in three different spectral bands. The measured spectral responses of the three cameras are shown in figure 1.

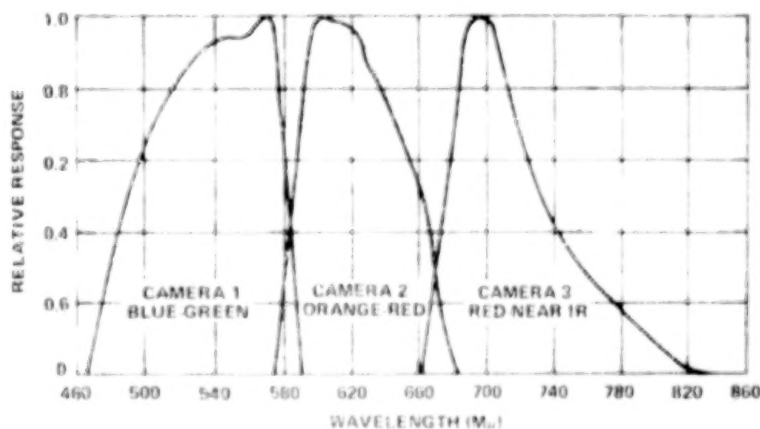


Figure 1. Spectral responses of the three-camera RBV system.

Each camera contains an optical lens, a shutter, the RBV sensor, a thermoelectric cooler, deflection and focus coils, erase lamps, and the sensor electronics. The cameras are similar, except for the spectral filters contained in the lens assemblies to provide spectrally separate viewing regions. The sensor electronics contain the logic circuits for programming and coordinating the operations of the three cameras as a complete integrated system and provide the interface with the other spacecraft subsystems. Table 1 shows the major camera parameters and their performance requirements.

Table 1  
RBV Camera Parameters

Parameter	Performance Requirements		
	Camera 1	Camera 2	Camera 3
Spectral bandpass (nm)	475 to 575 blue-green	580 to 680 orange-red	690 to 830 red-near IR
Video bandwidth (MHz)	3.2	3.2	3.2
Peak signal/rms noise (dB)	33	33	31
Relative aperture	f/2.66	f/2.66	f/2.66
Full field angle (deg)	16.2	16.2	16.2
Effective focal length (mm)	125.98 + 0.27 - 0.98	125.98 + 0.27 - 0.98	125.98 + 0.27 - 0.98
Highlight brightness (MJ/cm <sup>2</sup> )	0.78	0.78	1.2
Shading - inside 1-in. circle	≤15%	≤15%	≤15%
Shading - outside 1-in. circle	≤25%	≤25%	≤25%
Edge resolution (% of center)	80%	80%	80%
Image distortion	≤1%	≤1%	≤1%
Skew	≤±0.5%	≤±0.5%	≤±0.5%
Size and centering	≤±2%	≤±2%	≤±2%
Read horizontal rate (lines/s)	1,250	1,250	1,250
Active horizontal lines	4,125	4,125	4,125
Readout frame time (s)	3.5 (3.3 active)	3.5 (3.3 active)	3.5 (3.3 active)
Readout sequence	3	2	1
Three-camera cycle rate (s)	25	25	25
Exposure time matrix (ms)			
Expose 1	4.0	4.8	6.4
Expose 2	5.6	6.4	7.2
Expose 3	8.0	8.8	8.8
Expose 4	12.0	12.0	12.0
Expose 5	16.0	16.0	16.0

The three RBV cameras are aligned in the spacecraft to view the same nominal 185-km (100-nmi) square ground scene as depicted in figure 2. When the cameras are shuttered, the images are stored on the RBV photosensitive surfaces, and are then scanned to produce video outputs. To produce images with overlap of about 10 percent along the direction of spacecraft motion, the cameras are reshuttered every 25 seconds. The three cameras are scanned in sequence during the last 10.5 seconds of the basic 25-second picture time cycle. The video from each camera is serially combined with injected horizontal and vertical sync. The readout sequence progresses from camera 3, to camera 2, and finally to camera 1. The video bandwidth during readout is 3.5 MHz.

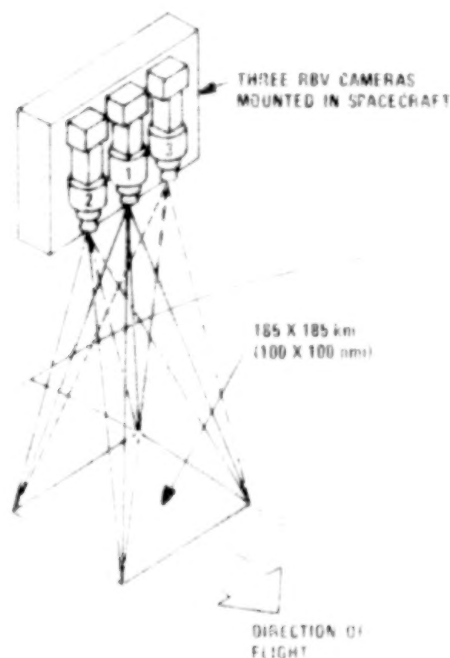


Figure 2. RBV scanning pattern.

To provide the geometric correction for each RBV scene, a reseau pattern is inscribed on the photoconductive surface of each RBV tube. The orientation of the camera with respect to the projection of the reseau pattern into the scene is provided by "camera feet," as indicated in figure 3. The camera lens reverses and inverts the scene so that the actual orientation of the reseau pattern on the vidicon in the camera is also inverted and reversed. Figure 3 also shows the orbit-track direction and shutter-motion direction. The shutter mechanism in each RBV camera consists of two adjacent blades with offset cutouts that sweep across the vidicon aperture to provide the precommanded exposure time to each portion of the

photoconductor. The shutter provides uniform exposure over the photoconductor within a maximum variation of  $\pm 5$  percent. Five shutter exposure times from 4 to 16 ms can be selected by command.

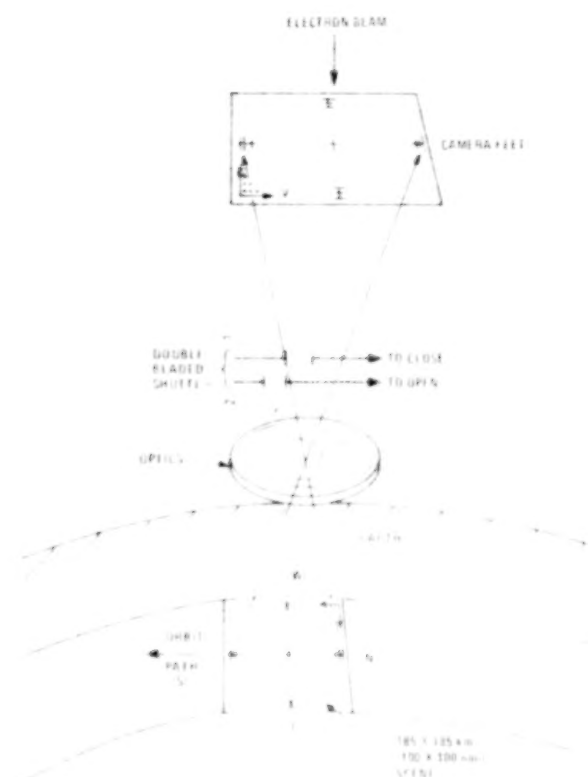


Figure 3. Camera-scene orientation.

The quality of the imagery produced by the RBV and transmitted to ground stations is influenced by several factors in the RBV system itself. These include resolution, geometric fidelity, exposure capabilities, and radiometric fidelity. These factors and their effects on imagery were measured for each camera during testing before launch and are compensated for during processing of the video data on the ground. Depending on scene contrast, the resolution of objects in each scene for the Landsat-1 and -2 RBV systems is nominally 80 meters.

### MSS SYSTEM

The MSS (figure 4) gathers data by scanning the surface of the Earth in four spectral bands simultaneously through the same optical system. The Landsat-1 and -2 MSS operates in the solar-reflected spectral region from 0.5 to 1.1  $\mu\text{m}$  wavelength as follows:

<u>Band</u>	<u>Spectral Response (Micrometers)</u>
4	0.5 to 0.6
5	0.6 to 0.7
6	0.7 to 0.8
7	0.8 to 1.1

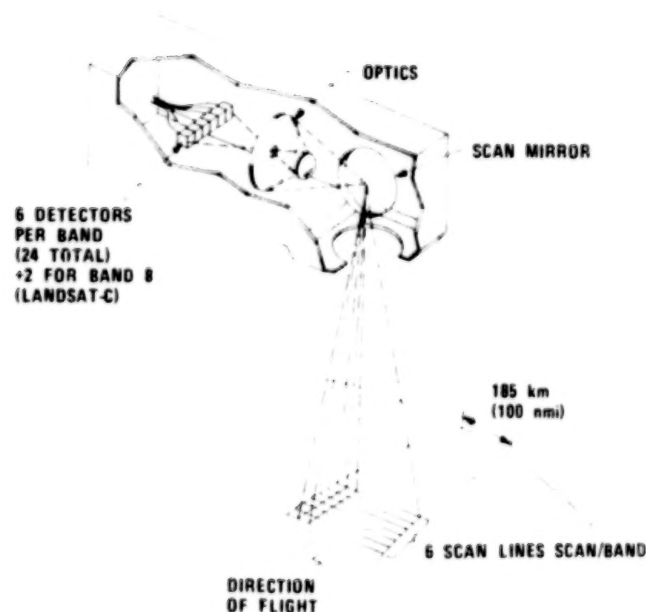


Figure 4. MSS scanning arrangement.

It scans crosstrack swaths of 185-km (100-nmi) width, imaging six scan lines simultaneously across the Earth in each of the four spectral bands. The object plane is scanned by means of an oscillating flat mirror between the scene and the double-reflector, telescope-type of optical chain. The 11.56-degree crosstrack field-of-view (FOV) is scanned as the mirror oscillates  $\pm 2.89$  degrees about its nominal position as shown in figure 4.

The instantaneous FOV (IFOV) of each detector subtends an Earth-area square of 79 meters on a side from the nominal orbital altitude. Field stops are formed for each line imaged

during a scan and for each spectral band by the square input end of an optical fiber. Six of these fibers in each of four bands are arranged in a 4-by-6 matrix in the focused area of the telescope (figure 5).

Each time the mirror scans, an image of the scan line is swept across the fiber. Light impinging on each glass fiber is conducted to an individual detector through an optical filter that is unique to the spectral band served, producing a video signal at the scanner electronics output for each of 24 channels. These signals are then sampled, digitized, and formatted into a serial digital data stream by a multiplexer. The sampling interval is  $9.95 \mu\text{s}$ , corresponding to a 56-m crosstrack motion of the IFOV.

The along-track scan is produced by the orbital motion of the spacecraft. The nominal orbital velocity causes an along-track motion of the subsatellite point of 6.46 km/s, neglecting spacecraft perturbation and Earth-rotation effects. By oscillating the mirror at a rate of 13.62 Hz, the subsatellite point will have moved 474 meters along-track during the 73.42 ms active scan-and-retrace cycle. The width of the along-track FOV of six detectors is also 474 meters. Thus, complete coverage of the total 185 km wide swath is obtained. The line scanned by the first detector in one cycle of the active mirror scan lies adjacent to the line scanned by the sixth detector of the previous mirror scan. Figure 6 shows this composite scan pattern.

The outputs from the detectors are sampled, encoded to six bits, and formatted into a continuous data stream of 15 megabits per second. During image data processing on the ground, the continuous strip imagery is converted to framed images with a 10-percent overlap of consecutive frames. This is accomplished by using RBV shutter activation times, giving the MSS images approximately the same area coverages as the RBV images.

On board the spacecraft, both the RBV and the MSS data are inputted to either a wideband video tape recorder for storage and delayed transmission to ground stations or a wideband modulator/transmitter for direct real-time transmission.

### **LANDSAT-C CHANGES**

For Landsat-C, to be launched in February 1978, both the RBV and the MSS sensors have been improved, as well as the National Aeronautics and Space Administration (NASA) Image Processing Facility (IPF).

### **RBV CHANGES**

The new RBV uses two panchromatic cameras that produce two side-by-side images rather than three spectral superposed images of the same scene. The ground scene will be viewed through the two RBV camera sensors as they are sequentially exposed, and the scene radiance is integrated on the photosensitive surface of the vidicon during the exposure period. During the readout period that immediately follows the exposure, the photosensitive surface is scanned, and the scene radiance is converted into a video signal.

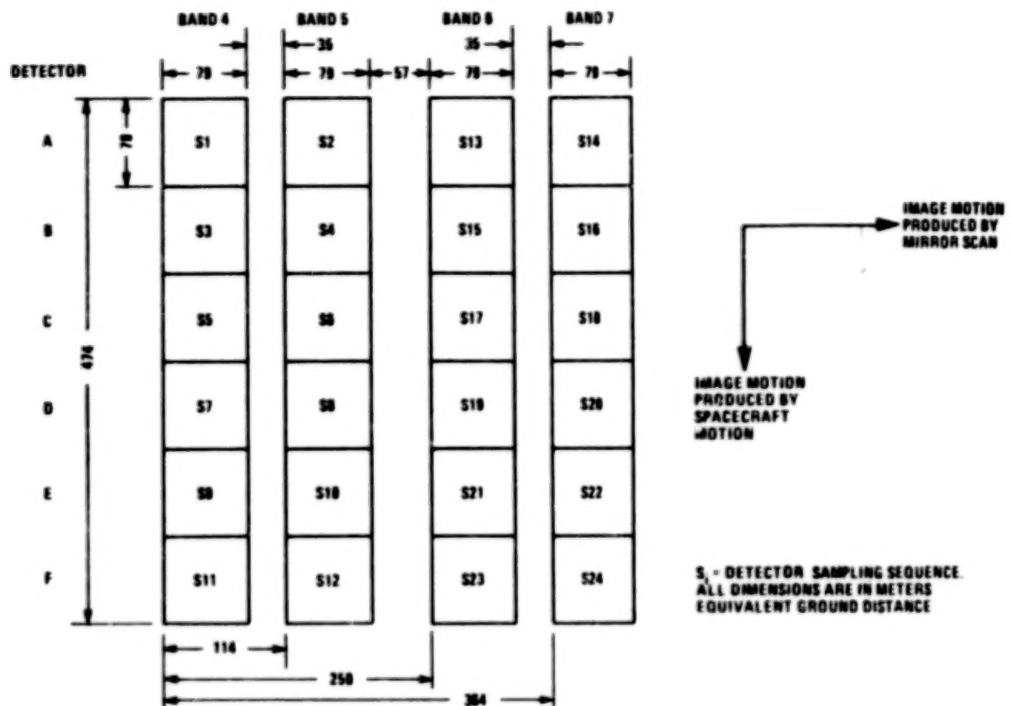


Figure 5. Landsat-1 and -2 light-pipe array and detector sampling sequence.

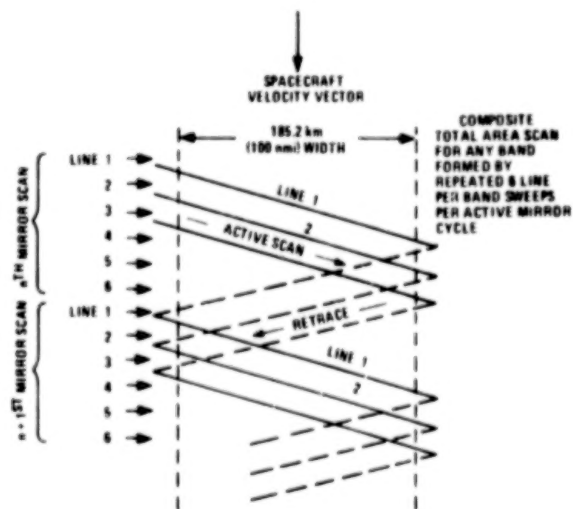


Figure 6. Ground-scan pattern for a single MSS detector.



Each RBV camera sensor is being designed to cover a  $98\text{-km}^2$  ( $53\text{-nmi}^2$ ) area. Landsat-1 and -2 cover a  $185\text{-km}$  ( $100\text{-nmi}$ ) square per frame as described previously. This change is being made to provide increased ground resolution for area mapping. To increase the ground resolution, a focal length of  $25\text{ cm}$  ( $10\text{ in.}$ ), twice that of Landsat-1 and -2, is required. Effective ground resolution will therefore be increased by a factor of two—from  $80$  to  $40$  meters. The two RBV cameras will be used to provide side-by-side pictures, each approximately  $98\text{ km}$  ( $53\text{ nmi}$ ) on a side, covering a total swath width of approximately  $183\text{ km}$  ( $99\text{ nmi}$ ). Camera shutter frequency will also be doubled to provide along-track overlap of adjacent frames (figure 7).

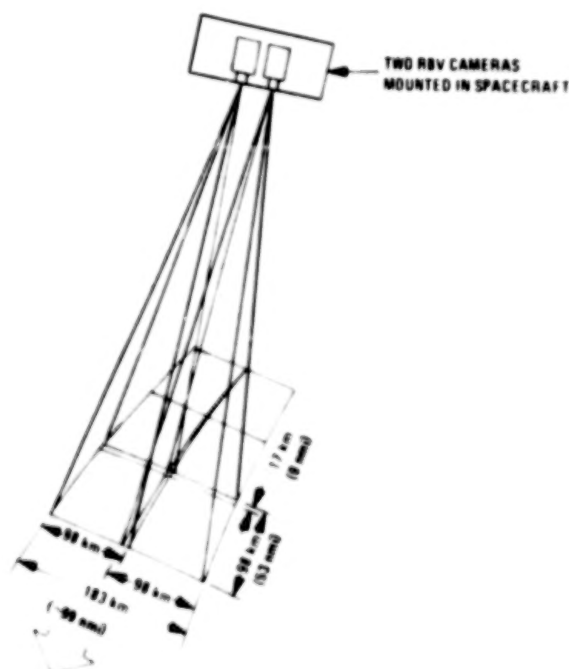


Figure 7. Landsat-C RBV scanning pattern.

Each camera can be operated independently of the other for either single-frame or continuous coverage. The two cameras will each have the same broadband spectral response (green into the near-infrared) of  $0.505$  to  $0.75\text{ }\mu\text{m}$ . The parameters that are of primary importance to users are:

<u>Parameter</u>	<u>Performance Objective</u>
Spectral bandpass	$505$ to $750\text{ nm}^*$
Video bandwidth	$3.2\text{ MHz}$
Peak signal/rms noise	$33\text{ dB}$

\*Denotes change from Landsat-1 and -2.

<u>Parameter</u>	<u>Performance Objective</u>
Lens, effective focal length	236 mm (nominal)*
Highlight irradiance	2.013 mW/cm <sup>2</sup> -sr*
Shading	≤15 percent within 2.5-cm (1-in.) circle ≤25 percent elsewhere
Image distortion	≤1 percent
Skew	≤+0.5
Size and centering	≤+2 percent
Read horizontal rate	1250 lines/s
Active horizontal lines	4125 per frame
Readout frame time	3.5 s (3.3 active)
Two-camera cycle rate	12.5 s*

The major parameter changes from Landsat-1 and -2 are the spectral band, timing, camera focal length, and improved shading corrections.

### **MSS CHANGES**

The MSS has been modified to include a fifth spectral band operating in the thermal infrared region from 10.4 to 12.6  $\mu\text{m}$ . Designated band 8, this additional band was added to the Landsat-C MSS by including two additional detectors as shown in figure 8. As illustrated, the two band 8 detectors are larger, providing a larger IFOV of 237 m<sup>2</sup>, as opposed to the 79 m<sup>2</sup> IFOV of bands 4, 5, 6, and 7. The band 8 detectors are also sampled at a lower rate. Bands 4 through 7 theoretically contain 3314 samples per detector per scan. That is, there are 3314 periods of 9.95- $\mu\text{s}$  duration in the 33-ms acquisition time (active portion of the mirror scan). Because of the reduced sampling rate, the band 8 detectors produce a maximum of 1104 samples each in the same 33-ms period.

In addition to enabling the sensor to collect data during the nighttime portions of the spacecraft's orbit, the thermal channel will be used for urban land-use identification (measuring temperature differences between manmade and natural objects), for monitoring temperature gradients in power-plant outfalls, for detecting urban "heat islands," and for other applications that are not possible with the present MSS sensor.

### **NASA INFORMATION PROCESSING FACILITY CHANGES**

Major changes have also been made to the NASA IPF at the Goddard Space Flight Center in preparation for handling Landsat-C data. High-density digital tapes (HDT) will replace 70-mm film as the archival medium for both RBV and MSS data. Radiometric and geometric corrections will be calculated for all data before recording on the HDT, and all film and

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\*Denotes change from Landsat-1 and -2.

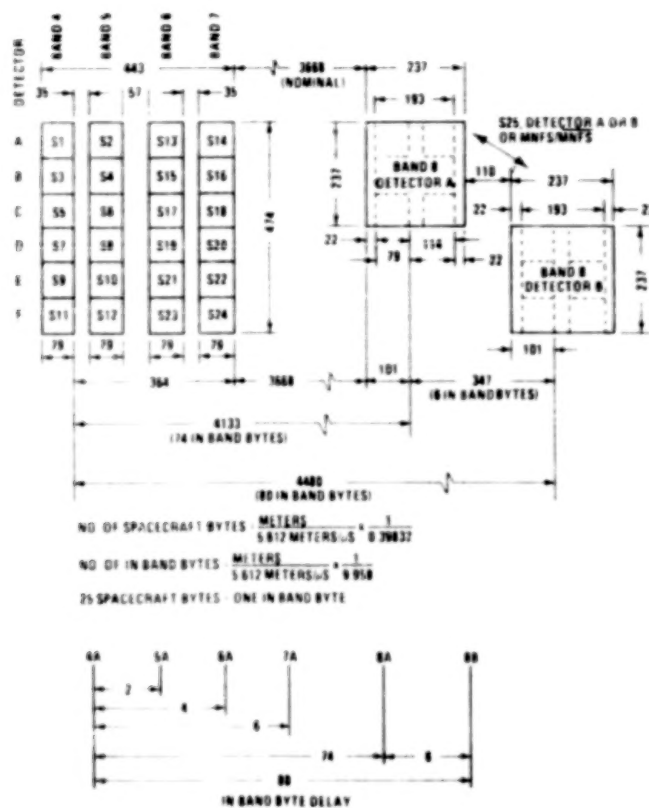


Figure 8. Landsat-C light-pipe array configuration.

computer-compatible tape (CCT) products for users will then be made from the HDT. Thus, the quality of the sensor data will be fully preserved, and full geometric corrections can be applied to all products. For the first time, both RBV and MSS data will be available to users in the highly useful CCT format. Steps are also being taken to drastically reduce the data delivery IPF turnaround time for all data products to 1 to 2 days. The digital processing approach will significantly contribute to this goal.

Figure 9 illustrates the payload data flow for processing Landsat-1 and -2 data in the present IPF. Figure 10 provides a flow diagram for Landsat-C data in the new IPF system. Landsat-C system performance characteristics are:

Radiometric calibration accuracy	Two quantum levels over full range
Geometric correction accuracy	
Nominal conditions with ground control points (GCP)	One pixel (without terrain-elevation correction), (99 percent of the time)

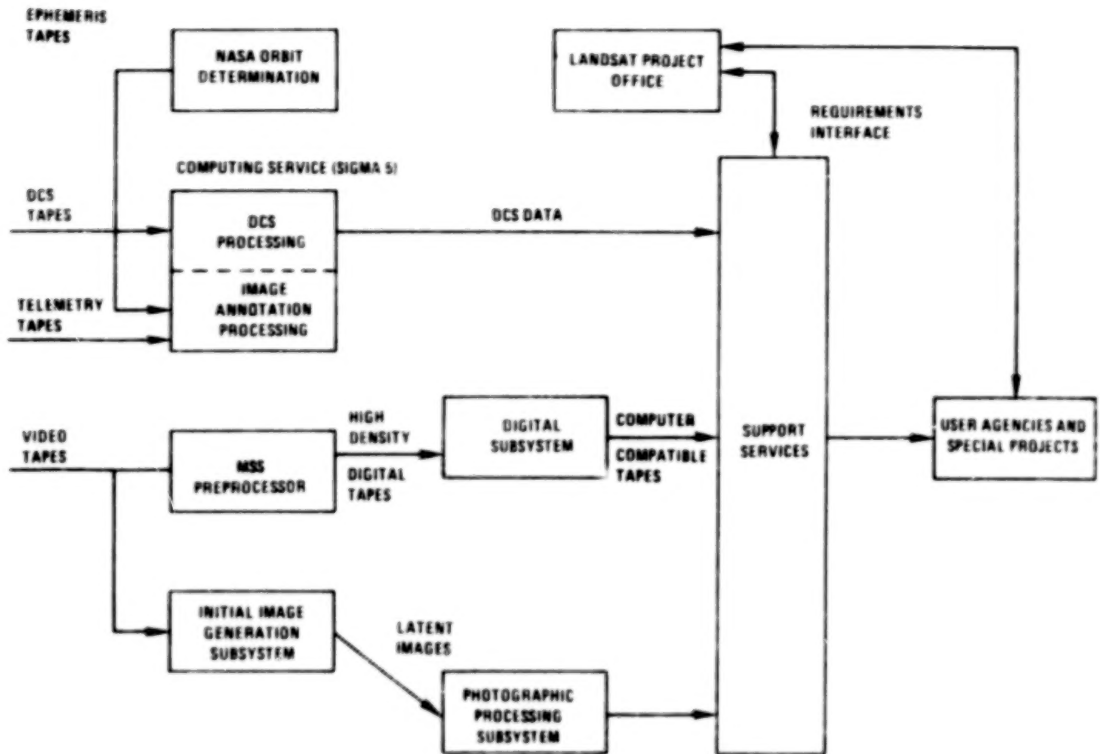


Figure 9. NASA Image Processing Facility.

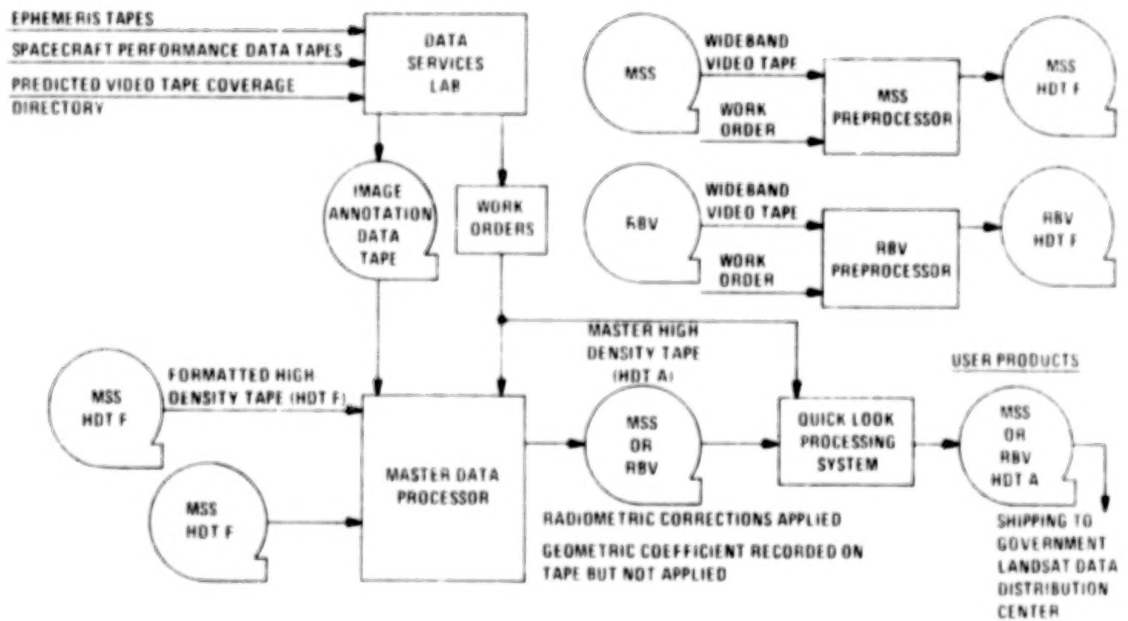


Figure 10. Video processing flow diagram for Landsat-C.

Without GCP	Commensurate with spacecraft and sensor performance data
Temporal registration	0.5 pixel (For RBV data, <0.5 MSS pixel accuracy)
Map projections	Space oblique mercator, universal transverse mercator, polar stereo
Resampling	Cubic convolution, nearest neighbor

The major hardware changes include revisions to the MSS preprocessor, the addition of an RBV preprocessor and master data processor, and the addition of a quick-look processing system (QLPS).

The QLPS, a major addition to the IPF, consists of a general-purpose capability to edit, format, and produce copies of selected HDT scenes in high-density tape, CCT, 241-mm black-and-white and color film, or paper formats. The QLPS contains a quick-look processor, a high-resolution film recorder, and a photoprocessing laboratory. Figure 11 shows flow diagrams of these three functional elements.

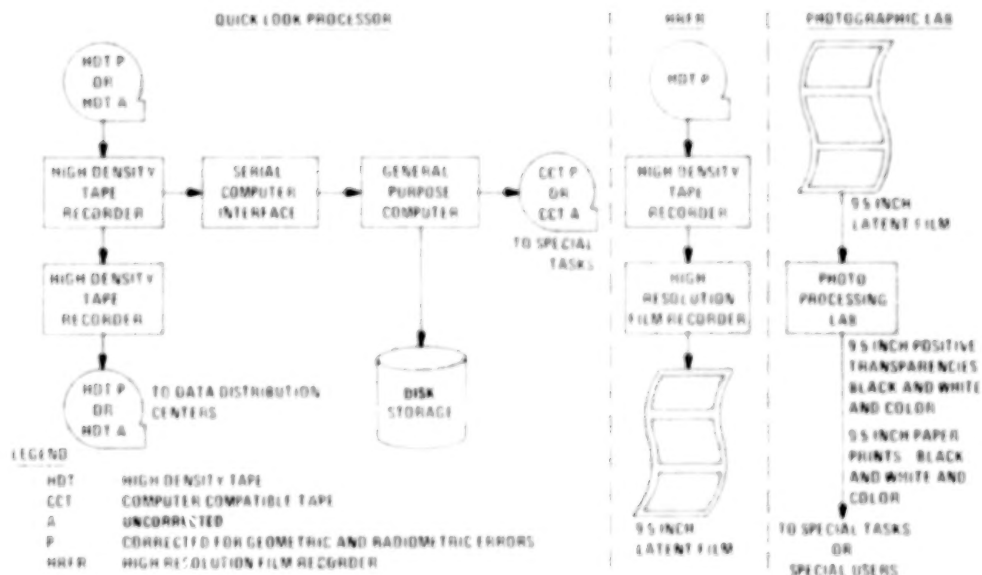


Figure 11. Quick-look processing system.

The quick-look processor inputs an HDT produced on the master data processor and generates edited/reformatted copies of user-selected scenes in HDT or CCT format. Band sequential HDT's and/or CCT's in pixel-interleaved or line-interleaved form can be generated for special

tasks. Computer tapes will be supplied in nine-track 800- or 1600-bpi densities only. The high-resolution film recorder (HRFR) inputs a fully corrected HDT and converts selected user-requested scenes to 241-mm latent imagery. The photographic laboratory inputs 241-mm latent imagery generated on the HRFR, processes the imagery, and produces black-and-white or color products in support of a limited number of special tasks.

User agencies, such as the Earth Resources Observation System Data Center, have taken steps to accept data from the IPF in high-density tape form. Equipment is available to produce CCT's and early generation film products from archival high-density tapes.

### LANDSAT DATA COLLECTION SYSTEM

In addition to the RBV and MSS, Landsat-1, -2, and -C are equipped with a data-collection system (DCS) that relays data from remote, automatic data-collection platforms to ground stations when a Landsat spacecraft can mutually view a platform and any one of the three U.S. ground stations (Greenbelt, Maryland; Goldstone, California; and Fairbanks, Alaska). The DCS flown on Landsat was the first prototype Earth-applications relay system to provide users with near real-time data collected from remote locations.

As shown in figure 12, the system includes remote data-collection platforms (DCP's), satellite relay equipment, ground receiving site equipment, and a ground data handling system. The DCP (figure 13) is connected to individual environmental sensors that are selected and provided by the investigator or user agency to satisfy their own particular needs. DCP's are being used to monitor local environmental conditions such as temperature, stream flow, snow depth, and soil moisture. Up to eight individual sensors may be connected to a single DCP, providing either digital or analog inputs. The DCP transmits the sensor data to the satellite, which, in turn, relays the data to the ground receiving site through an onboard receiver/transmitter.

The ground receiving site equipment accepts the data and decodes and formats it for transmission to the ground data handling system at Greenbelt, Maryland. The data are received in the Operations Control Center (OCC), where they are reformatted and written on magnetic tape and are then either transmitted direct to the user or passed on to the IPF for the further processing and cataloging required for dissemination to the user agencies. Data from any platform are available to the investigator within 24 hours of the time the sensor measurements are relayed by the spacecraft to the ground station.

Figure 14 shows the geometry involved in relaying DCS data. The satellite is at a nominal altitude of 920 km (497 nmi). The transmitting antenna of the DCP subtends an angle of  $\pm 70$  degrees from the vertical, and the ground receiving site visibility is nominally  $\pm 85$  degrees from the vertical. When the satellite is in mutual view of a transmitting DCP and one or more of the ground receiving sites, the message from the DCP is relayed to the receiving site and is transmitted over land lines to the OCC. The DCP's operate continuously, sampling the sensors periodically and transmitting a 38 ms burst of data containing all sensor channels

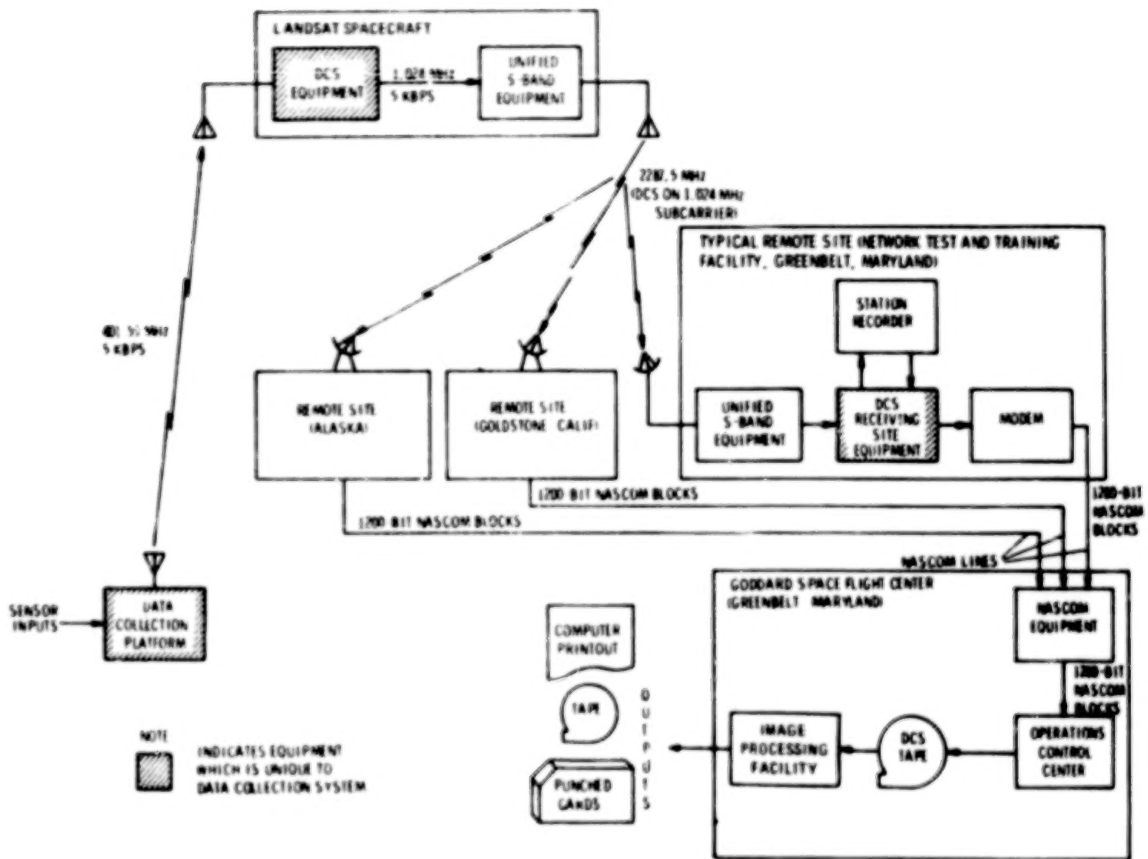


Figure 12. Data-collection system block diagram.

at intervals of either 90 or 180 seconds. Note that the satellite acts as a simple real-time relay with no onboard storage. The DCP transmissions are received at the ground receiving site immediately, except for small propagation and fixed system time delays.

The orbit parameters and the receiving site locations cause the spacecraft to be in mutual view of a platform located almost anywhere in North America and at least one of the three ground receiving sites during at least two orbits per day—one about 9:30 in the morning and the other about 9:30 in the evening. At least one message is relayed from each platform every 12 hours.

The DCS is designed to ensure that the probability of receiving at least one valid message from any DCP every 12 hours is at least 0.95 for as many as 1000 DCP's located throughout the United States.

Interference of signals from two or more DCP's transmitting simultaneously may cause incorrect or partial messages to be received. To minimize this possibility, the system uses error coding and other schemes to correct or identify messages that contain errors and to

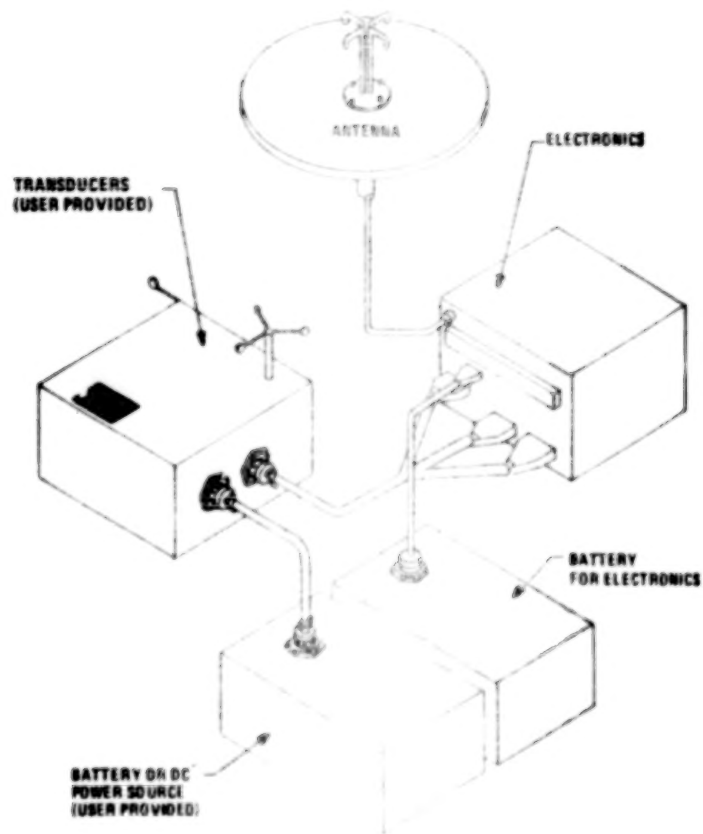


Figure 13. Data-collection platform.

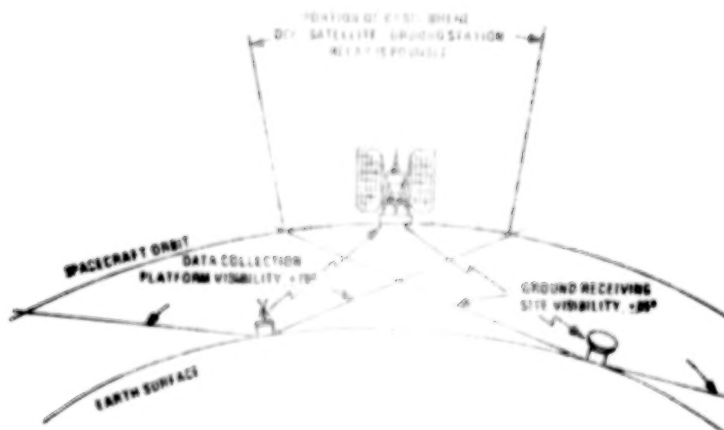


Figure 14. DCS geometry.



identify incomplete messages. The probability of erroneously indicating that a given message is valid (i.e., stating that a message that contains an error does not) is less than 0.001.

The experimental Landsat DCS has proven to be both reliable and highly useful. It has been so successful that an operational system, similar to the Landsat DCS, has been flown on board the National Oceanic and Atmospheric Administration's Geostationary Operational Environmental Satellite.

### THE NEXT STEP: LANDSAT-D

Now in the design and planning stage, Landsat-D will extend the availability of orbital Earth resources data beyond the lifetime of Landsat-C into the 1980's.

The principal sensor of the Landsat-D satellite is an advanced MSS called the thematic mapper. The design specifications for the thematic mapper call for the extension of the capability of the present MSS in virtually every significant aspect—the range of spectral coverage, number and sensitivity of individual spectral bands, ground resolution, quantization, and geometric accuracy. The primary objective of the thematic mapper is to observe land-cover characteristics, particularly vegetation. Such observations form an essential part of surveys of Earth resources and can be used in many applications.

Therefore, the bands tentatively selected for the thematic mapper have been chosen primarily on the basis of their ability to discriminate vegetation. Furthermore, they have been selected to avoid, as much as possible, the absorption bands of atmospheric water vapor. Because this factor is an important element in limiting signature extension (both temporally and spatially), avoidance of atmospheric water-vapor effects results in a significant improvement in Earth resources remote sensing capability. The bands selected and their particular value to various applications are:

- 0.45 to 0.52  $\mu\text{m}$ —Water depth measurements; soil/vegetation differences; deciduous/coniferous differentiation; land-use mapping
- 0.52 to 0.60  $\mu\text{m}$ —Vegetation density; growth-stage determination; vegetation vigor (disease detection); suspended sediments in water bodies; waste-disposal plume detection in water
- 0.63 to 0.69  $\mu\text{m}$ —Species differentiation for crop classification (chlorophyll absorption band); range land biomass estimation
- 0.76 to 0.90  $\mu\text{m}$ —Water-body delineation; ratioed with 0.63- to 0.69- $\mu\text{m}$  band for vegetation and biomass studies
- 1.55 to 1.75  $\mu\text{m}$ —Vegetation moisture conditions (indicator of vegetation vigor); snow/cloud differentiation; surface water mapping; soil moisture measurement (after rainfall or irrigation)

- 10.4 to 12.5  $\mu\text{m}$ —Crop classification and disease detection; vegetation density and cover-type identification; urban land-use identification (temperature differences between manmade and natural objects); monitoring temperature gradients in power-plant outfalls, urban "heat islands," river/lake/estuary current, etc.

In addition to better multispectral sensing capabilities, the thematic mapper will have a greatly improved IFOV—from 80 meters for the present MSS to 30 meters for the thematic mapper. Because this improvement will permit analysis of smaller areas on the ground, it will result in substantial gains in all applications areas.

An MSS essentially identical to that flown on Landsat-C may also be included on Landsat-D, differing only in some minor modifications necessitated by the planned reduction in altitude of Landsat-D to 705 km (380 nmi). Including an MSS in Landsat-D would provide:

- A reliable, space-proven backup sensor to the new thematic mapper
- A continuation of current Landsat/MSS data for use by those who either do not need the improved thematic-mapper data or do not have the necessary facilities to receive or analyze that data
- Precursor data to assist the user in selecting only good coverage before processing thematic-mapper data
- Transitional data to aid users in converting to the improved thematic-mapper data

In addition to its improved sensor, Landsat-D will also feature faster data handling and distribution. For remotely sensed multispectral data to be truly practical for many potential operational users (agricultural analysts, hydrologists, etc.), it must be received by them in usable form within 48 to 96 hours after overpass. Promptness in receiving data products is one of the most critical aspects of the Landsat system. Landsat-D will be thoroughly integrated with the needs of operational users. It will include: improved preprocessing of all data, central data processing, and archiving and retrieval; low-cost receiving and data centers for large volume users (such as the U.S. Department of Agriculture); and will provide maximum efficiency and economy in utilization by state, regional, and foreign users. Featuring the rapid electronic transmission of all data, Landsat-D is being designed to reduce the time between satellite imaging and user reception of data to the required 48 to 96 hours.

The system will provide two data links to the ground. For both MSS and thematic-mapper data, the first link is directly from the satellite to domestic and foreign ground stations as the satellite passes over their reception areas. The second link, for thematic-mapper data only, is via the Tracking and Data Relay Satellite System (TDRSS). The data are transmitted to a TDRSS satellite that is in stationary orbit and are relayed to the TDRSS receiving station. The TDRSS receiving station then transmits the data via a domestic communications satellite to a central data processing facility that, in turn, relays the data to any local data-distribution center equipped to receive it. This link, via TDRSS and the communications satellite, will

therefore permit global acquisition and relay capabilities, providing rapid access to thematic-mapper data for users throughout the world. It will also eliminate the need for an onboard video tape recorder, a weak link in the present Landsat system.

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## REMOTE SENSING OF WATER QUALITY

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### ABSTRACT

Remote sensing from aircraft has been used to determine water content in areas such as the New York Bight. Extension of the techniques developed to satellite sensing of the Chesapeake Bay will begin in 1978 with the launch of Nimbus-G.

Remote sensing offers a number of interesting possibilities for investigating a reasonably large body of water, such as the Chesapeake Bay, coupled with some disadvantages. The chief advantage of remote sensing is that it offers the opportunity to cover large areas in relatively short periods of time. Low-altitude satellites traveling at about 7 km/s can cover the Chesapeake Bay in about 1 minute so that the entire Bay can be studied under almost identical conditions of solar illumination.

Aircraft take longer to cover an area because of speed difference and narrower swath width from a sensor. Swaths of 1600 km are quite normal from satellites at near 1000-km altitudes, whereas aircraft swath widths, even from U-2 altitudes near 20 km, are only approximately 37 km. Aircraft sensors offer an advantage in that they can achieve much higher spatial resolutions than spacecraft sensors with considerably lower cost instrumentation.

Reasonably high-resolution sensing (80 by 80 meters) is accomplished from the Landsat series of satellites using the multispectral scanner, but such resolution is achieved at a considerable cost in sensor swath width (186 km) and infrequent coverage (once every 18 days), cloud cover permitting. In addition, the dynamic range of the Landsat sensor is optimized for land targets that reflect much more than water, so that subtle changes in water color are difficult to detect.

Although new systems specifically devoted to oceanographic measurements are being developed, for the foreseeable future, such spacecraft systems will not have Landsat-type spatial resolution, and aircraft sensing will be needed as a supplement. Both spacecraft and high-altitude aircraft sensors suffer from a common problem—atmospheric interference in the form of backscattered sunlight in the visible and near infrared and water-vapor absorption

in the thermal infrared, in which water temperatures are sensed. Figure 1 illustrates the backscattered sunlight problem by comparing two spectra taken over the same area of the ocean within 23 minutes of each other at 14.9 and 0.91 km altitudes.

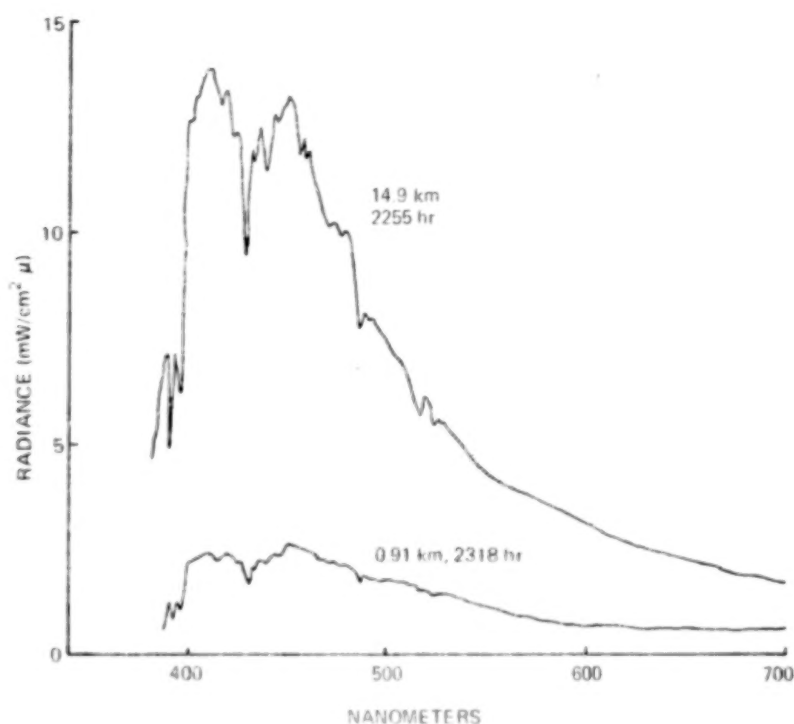


Figure 1. Upwelling radiance over Catalina Channel at high and low altitudes.

The skylight not only adds to the total signal to be sensed, but sunlight reflected from the ocean is scattered out of the column viewed by the sensor so that the total signal reaching a high-altitude sensor may consist of 80 percent or more skylight, and, 20 percent or less will therefore contain information about the water below.

The result of atmospheric interference in photographic sensing from high-altitude aircraft is that pictures taken with film sensitive in the visible are dominated by skylight. Although infrared film provides better atmospheric penetration, water penetration is poor in the infrared, and little information about water content is obtained. Photography can provide an excellent source of information about shoreline activities and vegetation, but is of very limited value in sensing water content from reasonably high altitudes. However, it can provide ancillary information about factors that influence water quality, such as location of marinas, number of vessels berthed in selected areas, and location of factories and tank farms near shorelines.

Water quality and content can best be remotely sensed by multichannel scanning radiometers. These sensors can have much higher signal-to-noise ratios than photography, they are more accurate quantitatively, and they can operate in spectral regions not covered by film, such as the thermal infrared. The electrical signal generated by these sensors can be more readily processed for reduction of atmospheric effects and can be used for multispectral qualitative analysis. The disadvantages of scanner systems are that the scanners are expensive and data recording and processing equipment are more expensive and complex than those needed for photography. For satellite and high-altitude aircraft sensing, however, the advantages far outweigh the disadvantages and scanner systems predominate.

A multichannel ocean-color scanner was built for use on a National Aeronautics and Space Administration U-2 aircraft as a predecessor to a similar sensor to be flown on Nimbus-G. The aircraft sensor has ten spectral bands as shown in table 1.

Table 1  
Parameters of the U-2 Ocean-Color Scanner

Channel	Center Wavelength (nm)	Bandwidth (nm)	Radiance (Gain $\times$ 1) $\text{mW/cm}^2 \mu\text{m}$
1	433	22.5	40.1
2	471	21.5	26.0
3	509	27.5	23.6
4	547	24.5	14.7
5	583	25.0	11.8
6	620	26.0	10.0
7	662	22.0	7.55
8	698	20.5	5.0
9	733	22.5	11.9
10	772	23.0	3.47

The radiance column shows the input to the sensor in  $\text{mW/cm}^2 \mu\text{m}$  that will produce saturation. All channels, except channel 9, are optimized for water and will saturate over most lands, targets, or clouds.

This particular sensor has rarely been used over the Chesapeake Bay. It is normally used only in conjunction with surface truth expeditions that cover large areas of the ocean out to 100 nmi. On two occasions, it was operated over the Chesapeake Bay in conjunction with photographic missions for studying shorelines. Although surface truth was not available, considerable apparent change in water mass can be seen in the false color image in figure 2. Made with enhanced data from channels 2, 5, and 7, this image covers the Bay from slightly



Figure 2. False-color image of  
Chesapeake Bay



north of the Susquehanna to the mouth of the South River. Spatial resolution is about 70 meters at nadir.

At the time the imagery was acquired (July 22, 1974), it was assumed that the bright coloration in the Bay was attributable to scattering by suspended materials (sediments and organic) and that the darker the image, the lower the concentration of suspensoids. During the same flight, the New York Bight off Sandy Hook was covered as shown in figure 3, with all sensor parameters the same as in the coverage of the Bay. The New York Bight image shows the plume from the Hudson River, a U-shaped acid waste dump, and some relatively clean ocean water.

In a case such as the Hudson River Plume, in which the water is deep and there is surrounding water with small amounts of suspended materials, quantitative estimates of suspensoids have been fairly successful. Measurements made from a National Oceanic and Atmospheric Administration (NOAA) ship at 35 locations in the New York Bight were compared with simultaneous measurements made by the scanner on the U-2. Upwelling radiance showed a general increase with sediment concentration as shown in figure 4. Analysis was performed using the characteristic signature technique shown in figure 5. This technique requires that a mean be calculated for each water-picture element in the image and that deviations from the mean be determined for each truth site for each spectral band. The sediment signature that best agreed with surface truth resulted in the computed sediment as shown in figure 6 compared with truth measurements.

Although the New York Bight results indicate that sensing of total suspended material is a promising area for remote sensing, it also showed that it will be very difficult to identify and quantify suspensoids in a system as complex as the Chesapeake Bay. An opportunity will be available in 1978 to carry out such investigations with reasonable frequency when Nimbus-G is launched carrying the coastal-zone color scanner (CZCS). This sensor will provide color scanning in five spectral bands and thermal scanning in one band with 800-m resolution and 1500-km swath width for frequent coverage. Data from this scanner will be available at nominal cost from the Environmental Data Service of NOAA in Suitland, Maryland. Some characteristics of the CZCS are:

- Spectral bands

- 443  $\pm$  10 nm
- 520  $\pm$  10 nm
- 550  $\pm$  10 nm
- 670  $\pm$  10 nm
- 750  $\pm$  50 nm
- 10.5 to 12.5  $\mu$ m

- Spatial resolution—0.865 milliradians, 825 m at nadir





Figure 3. False-color image of  
New York Bight.

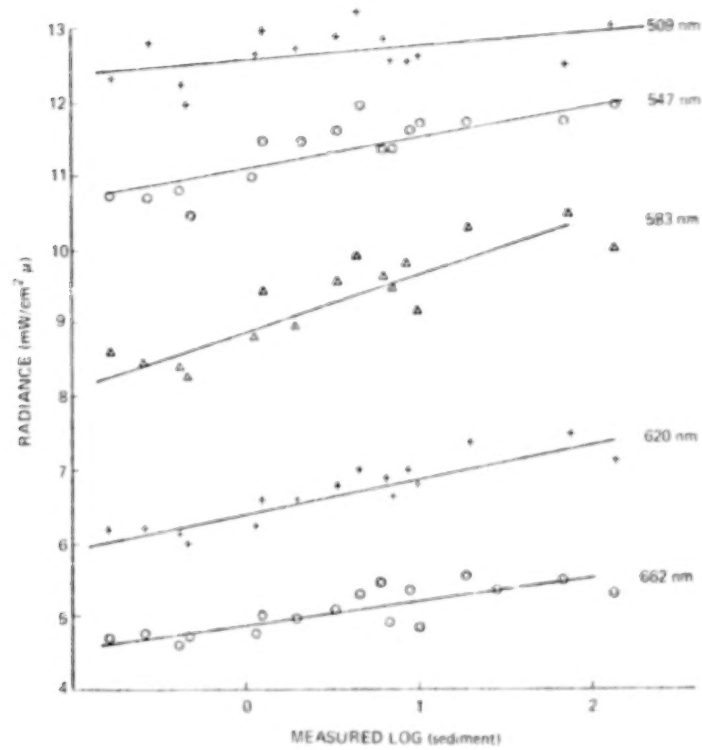


Figure 4. Upwelling radiance increase with sediment concentration, New York Bight.

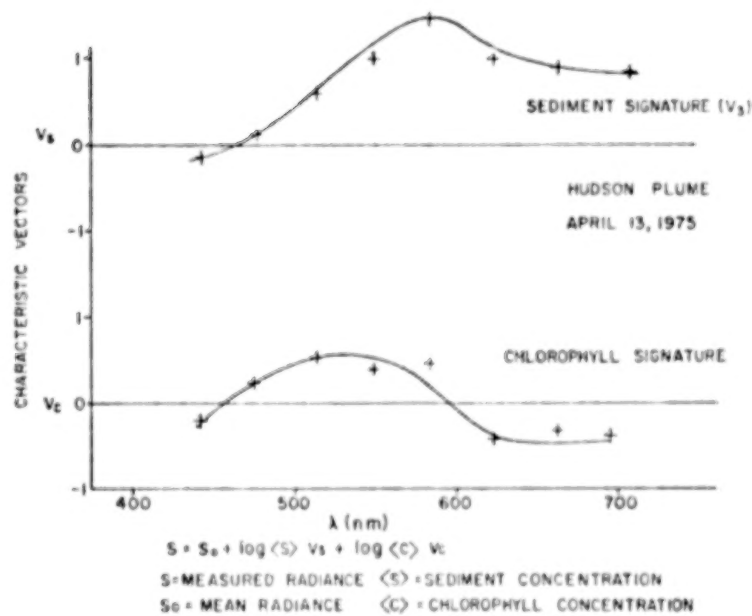


Figure 5. Characteristic signature technique analysis, Hudson River Plume, April 13, 1975.

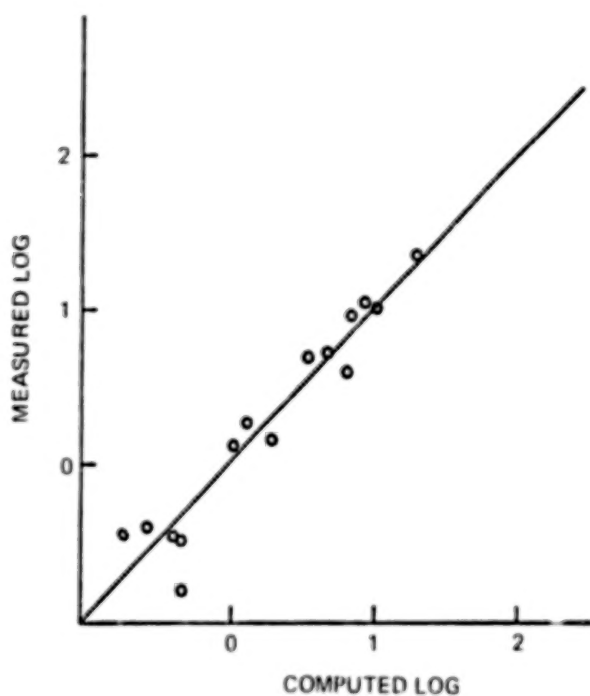


Figure 6. Computed sediment versus measured sediment of the Hudson River Plume, April 13, 1975.

- Operation—Day, all channels; night, 10.5 to 12.5  $\mu\text{m}$  only
- Glint avoidance—Tilt of scan mirror  $\pm 10^\circ$  along track for  $\pm 20^\circ$  pointing
- Swath width—Full swath, 1566 km; narrow swath, 700 km

## ACOUSTIC REMOTE PROBING OF THE ENVIRONMENT

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### INTRODUCTION

This paper is an introduction to the spectrum of applications of acoustics as a truly remote probe for use in profiling the physical parameters of our environment. Classical application of acoustics under the term "sonar" has been used in bathymetry and detection of point targets such as ships or fish. In the field of geophysics, it was the geologist who first used acoustics to profile physical parameters of the Earth with seismic sounders. In oceanography, acoustics have been used for more than a decade as a remote probe for profiling the stratification of the oceans and the structure of bottom sediment. Within the last decade, acoustics, as well as numerous RF techniques, have been applied for vertically profiling physical parameters of the atmosphere. I will discuss what the meteorologist and oceanographer can soon expect to routinely achieve with instrumentation that uses acoustic probes to remotely obtain physical parameter profiles in both the atmosphere and underwater.

But first, as an aside, one of the problems that periodically troubles the technologist is that commonly used terms with broad definitions begin to lose their usefulness in the growth toward precise communications. As a technology grows and its domain broadens, new terms are needed and, in some cases, existing terms require revised and perhaps more restrictive definitions. A case in point seems to be that of "remote sensing." Because I am sensitive to definitions and because this is a remote sensing conference, I would like to point out that I consciously distinguish between "remote sensing" as a strictly passive concept and "remote probing" as an active one. I use the word "sensing" restrictively to imply that the source of field energy being detected was *not* originally the hardware associated with the sensor but rather a source over which control is not directly imposed. On the other hand, "probing" implies that active control exists (usually in hardware) over the source of the "probe" (usually an electromagnetic or an acoustic field). This distinction and an identification of the term "probe" to the emitted field have helped me to organize thoughts and communications. Value of the distinction lies in the fact that control over the probe blanketly provides an added dimension to the extraction of information from energy scattered by interaction of the probe with physical manifestations of environmental parameters. I also tend to use the word "tool" when speaking about either an electromagnetic or an acoustic field. I suppose that this is simply because I view the

field as the "means" of obtaining the "end" product of information about environmental parameters.

The ability to scan large volumes at distances remote from hardware for three-dimensional distributions of a host of environmental parameter data is the ultimate payoff of both remote sensing and probing systems. Although no remote system can claim to have attained such a goal, the increase in information obtainable through present techniques represents a quantum increase in collected data that then must be processed. The words "collected" and "processed" are more naturally used instead of talking about "measuring" the parameter of interest because it appears that the farther away you get from the physical manifestation of the parameter, the more indirect and error-prone the measurement; then more processing is required to extract from the data only the information needed for estimating the parameter. The processing can be viewed as the second edge of a double-edged sword, and it behooves the user to make careful selection of his sensing and probing techniques in order to minimize the self-inflicted costs caused by the processing edge facing him.

The general problem reduces to one of comparing the payoffs to the costs of using remote tools: Is the reduction in precision and accuracy inherent in the indirect measurement worth the increase in resolution and amount of data that can be collected in a remote fashion? It appears that the question can be answered in the affirmative for many satellite-borne sensing systems, but not yet for oceanic and atmospheric acoustic probe systems.

### ACOUSTIC PROBES OF THE ATMOSPHERE

Techniques are being developed for probing the atmosphere using acoustic fields as tools in much the same manner as techniques using electromagnetic (EM) fields. The EM fields are launched from satellite, aircraft, and ground-based stations, but acoustic fields cannot be launched from satellites and are now being used only from ground-based stations. Also, it is not unreasonable to expect that remote acoustic sensing could serve as a meteorological tool in the future. One indicator of this possibility is that storm-generated infrasound can be observed over distances of 1500 km.

Much effort has been expended by the Wave Propagation Laboratory (WPL), the Environmental Research Laboratories (ERL), and the National Oceanic and Atmospheric Administration (NOAA), to develop remote techniques for probing the atmosphere from both the ground and the decks of ships at sea. Although much of this effort includes techniques that use EM probes in the high-frequency, microwave, and optical portions of the spectrum, this paper is restricted to remote acoustic probes. Only these probes offer a wide range of potential application for monitoring and studying our ecosphere. However, I will touch on the case in which the close relationship in wavelength of EM and acoustic frequencies in the atmosphere enable these tools to play supportive roles in providing a hybrid remote probing system.

Systems that employ acoustic probes in the atmosphere are called "acoustic echo sounders" or "echosounders." These terms have been applied, most naturally, by the meteorologist. Acoustic energy, usually in the form of a finite and rectangular burst, containing many wavelengths in the emitted field undergoes modification because of propagation effects and scattering caused by scattering centers whose refractive index differs appreciably from that of the surrounding medium. Some characteristics of the medium along the propagation path can be determined by detecting the forward scattering (propagation) field. Characteristics of the medium can also be determined by detecting the scattered field in directions other than the forward direction.

A wide range of studies of atmospheric phenomena, as well as practical atmospheric monitoring applications, have used remote acoustic probes. I will mention only a few of these simply to convey the realm of applicability of the various techniques. Measurements of changes in both amplitude and phase of acoustic waves propagating through various turbulent structures in the atmosphere have provided useful data for estimating the probable limits of acoustic probing in the atmosphere. Although systems based on propagation phenomena of the acoustic field will probably not be as useful in environmental monitoring applications as systems that rely on scattering phenomena, they are needed to characterize the expected deformation of the probe along the path from source to scattering center to detector.

Systems that use scattering phenomena have been implemented with an assortment of geometries. There have been monostatic, bistatic, and compound bistatic configurations. Probably the most practical use of acoustic remote probing has been a WPL test installation of a wind-shear detector at the Stapleton Airport in Denver. The system has a compound bistatic geometry that permits vertical profiling of the horizontal components of the wind vector from 30 meters to 1 kilometer. When probing the atmosphere from the ground, the choice of system configuration can be allowed to be governed by factors other than constraints of location of hardware. But, when probing above the sea surface, multi-static configurations are impractical because of the added deployment difficulties.

A large number of mechanisms that result in density gradients or discontinuities in the atmosphere occur on a broad spectrum of spatial scales. Among these mechanisms, those that produce gradients are thermal and humidity stratification and velocity fields. Among the discontinuities are rain, snow, fog, and cloud hydrometeors, dust and pollen particulates, and thermal plumes and inversions. Many meteorological and environmental parameters and phenomena can be detected or monitored directly or indirectly using these scattering mechanisms. The basic parameter observable indirectly through the Doppler shift in scattering from the small discontinuities is the wind velocity that can be obtained in profile. Gravity waves and other wave-like motions in the atmosphere can be detected indirectly by observing motion of spatially large discontinuities, such as temperature inversion layers. Depending on spatial scale, turbulence can be observed either by Doppler

spectral broadening of the field scattered by entrained discontinuities or by refractivity fluctuations.

Methods of profiling temperature by strictly acoustic probing that make use of multiple acoustic frequencies are neither reliable nor accurate. But, a hybrid technique has been developed that uses both acoustics and electromagnetics. After transmitting a low-frequency sinusoidal acoustic pulse vertically, continuous wave (CW) radar is used to track the pulse as it propagates. If the wavelengths are chosen so that the acoustic wavelength is one-half the electromagnetic wavelength, the RF energy is Bragg-scattered by the acoustic wavefronts. Enough energy is backscattered by the entire acoustic pulse for it to be detected and analyzed for Doppler frequency shift. Continuous tracking of the Doppler frequency produces a sensitive measure of the speed of the acoustic pulse that can be related to the temperature profile. Spatial resolution is proportional to the acoustic beam width and pulse length that is the exact size of the acoustic probe in the atmosphere.

For those interested in further pursuing the topic of remote probing in the atmosphere, two NOAA publications will serve ideally as the next step. A collection of reprints bound under the title of "Remote Sensing of the Troposphere" edited by V. E. Derr, and "Collected Reprints: 1974-75, Wave Propagation Laboratory," together serve as repositories for most of the applications-oriented papers produced by WPL on both remote probing and remote sensing of atmospheric parameters by both acoustic and electromagnetic techniques.

#### UNDERWATER ACOUSTIC PROBES

Development of acoustic techniques of remote acoustic probing in water was initiated a few years ago by the Engineering Development Laboratory (EDL) of the National Ocean Survey (NOS). The feasibility of using crude hardware for remote probing of water currents has been demonstrated to distances of about 20 meters with current velocity resolution of 16 cm/s and spatial resolution of about 3 meters. This was done with a peak acoustic power of only 2 watts focused in a narrow beam at about 280 kHz. Extrapolating these results, along with a theoretical study performed by WPL to determine the feasibility of this concept and assumptions on physical limitations associated with future operational deployment, produces conceptual devices with strong growth potential in both operational environmental monitoring and environmental research.

Although the initial goal of this effort was to provide a possible backup to measuring tidal current flow in very high peak current regimes (12 knots was expected at one time in Cook Inlet, Alaska), the concept has evolved much wider applicability not only in the lower current, high-resolution regimes, but also for probing for other physical parameters as well. Two development projects are underway at EDL for producing probes to profile water currents from different platforms. One platform is a submerged low cross-section body that would either rest on the bottom in moderate depths (to about 100 meters) or



be deployed on conventional moored systems in multiple units at much greater depths. The second platform is a ship that, while underway, would provide the water-current profile below the ship. The fixed platform would be used to obtain extended-time water-current profile data at one geodetic point as is needed in tidal-current prediction models. Although a single underway platform would provide higher resolution in the spatial dimension, it would not provide the synoptic view of a region that can be obtained from a distribution of many fixed stations in the region. A fundamental use of high-spatial resolution water-current profile data in tidal-current survey operations would be to ensure that the spatial sampling that must be performed minimizes the effect of spatial aliasing of tidal energy in the parameters of the tide prediction models. Also, because an underway current probe profiles currents along its path of travel, the resultant data on water-mass flux distributed over a known area would be valuable in models of water-pollutant mobility. Another application of the underway system would be to study the effects of density fronts in the water. Because these fronts play such an important role in atmospheric weather, one would expect them to play a comparable role in the seas.

As with atmospheric probing of winds, the probing of water currents can be done with various configurations in geometry. Nevertheless, a monostatic system appears to have the best chance of passing the critical test of ease of deployment at sea. As with atmospheric probing from a ship, bistatic geometries could be implemented by spanning as much of the overall ship as possible with transducer locations. The resulting small baseline would provide little advantage at ranges of kilometers. Even though the true multistatic configuration appears to be impractical, it can be approached by translating the probe axes of a multi-axis monostatic system so that they intersect not in a common probed volume, but in a common observation point. Each axis would still function as an independent probing channel in a monostatic manner. The data obtained in each channel at a common point of intersection would eliminate the error in resolving a resultant vector from components obtained from physically disjointed spatial volumes. In this configuration, the advantage of detecting other than back-scattered energy with a true multistatic geometry would be lost. With the configuration in which the channel axes intersect at the location of the transducers, estimates of profiles of any vector parameter can be made only when it can be justified to assume that the macro-volume spanned by the entire set of probing channels contains surfaces on which the vector parameter is constant.

The ideal geometry from which to operationally profile water currents with a stationary platform appears to be one with three probe axes oriented either orthogonally or along another set of basis vectors designed to minimize parameter measurement error in a preferred direction. In the case of a platform resting on the bottom with a probe system designed to primarily measure horizontal currents, a horizontally uniform distribution of probe axes all inclined at 45 degrees to the vertical is ideal. In most applications, it would be reasonable to assume that horizontal planes are surfaces of constant current velocity (at least in the macrovolume spanned by the probe axes) even at the water surface. The profile of axial components



produced by each probe channel could then be easily resolved into the profile of vertical and horizontal components of current velocity.

When the probing platform is a ship, the two most significant problems encountered are caused by ship motion. One problem is caused by the wave-induced dynamics of the ship, and the other is the definition of the inertial reference against which the current velocity is to be measured. The present approach to solving the dynamics problem is to use pairs of probes whose axes are in the same plane to obtain only a single horizontal component of current velocity. This transducer-head configuration has been used for years and is known as "janus." Averaging the Doppler shifted data from these two probes cancels the contribution that is attributable to angular motion in the plane about their point of intersection. This point can be translated to the center of pitch or roll of the ship. The inertial reference problem is solved simply by using the backscattered returns from the bottom or known layers of no motion with which the horizontal velocity of the ship can be deduced. Horizontal water currents are thereby referenced to the Earth.

Among the goals in the development of a remote current probe for use in operational tidal-current surveys by NOS is the desire for a reduction in the high costs of deployment and retrieval. A self-contained unit that is small and light enough to be either dropped from a helicopter or simply kicked off the side of a ship without a tether would undoubtedly simplify the deployment process. With the advantages of emerging low power and cost in digital processing and high-density data storage, after sinking to the bottom, the unit could be left unattended for months to acquire the long-time history required by tidal-current prediction models. Retrieval of individual units after acoustically triggering floatation mechanisms would be much easier than recovering extended strings of current meters.

It does not require much imagination to take a step backwards and observe that a set of strong backscattered returns will be obtained from either the surface or the bottom, or both, depending on the configuration and the location of the platform. In a three-axis system resting on the bottom, the two most obvious and immediate uses for the surface returns are, first, vertical orientation and, second, tide levels. With the simple deployment techniques mentioned above, the need to dynamically establish a vertical is fundamental. Although subsequent alignment with respect to the vertical can be done mechanically, it is most efficiently accomplished in the processing algorithms. Using the same hardware to determine the tide levels provides additional operational cost reduction.

A simple but interesting example of an environmental parameter measurement that relates the domains of the oceanographer to those of the meteorologist is barometric pressure. A recent system produced by EDL for tide measurement, called the Offshore Tide Telemetry System (OTTS), incorporates an extremely sensitive and stable absolute pressure sensor. One of these sensors is mounted on a structure resting on the bottom, and the other is mounted in a tethered surface buoy. These sensors measure absolute pressure at their respective locations. With an estimate of the average water density, the measurements of total pressure

both at the surface and on the bottom are used to estimate the tide height. OTTS deployments in the New York Bight telemeter local tide levels within an error bound of 3 centimeters. Alternatively, by directly measuring the tide level with a remote acoustic probing system resting on the bottom, by sensing absolute pressure at the same location, and by estimating average water density between this location and the surface, we can estimate the barometric pressure above the surface. Atmospheric pressure could be measured to within 1-percent error. An important aspect of this system is that a surface buoy is not necessary for obtaining both tide-level and barometric pressure estimates. This eliminates a potential navigation hazard and reduces deployment costs.

In addition to the time of return of the surface scattering to determine the tide level and vertical, much more information about the surface is contained in both the amplitude and frequency spectra of the surface return. Because the axes of the acoustic probe channels are inclined with respect to the surface, the acoustic probe scans the surface in time. The effect of this scanning is to transform spatial parameters of the surface into temporal parameters of the scattered acoustic energy. The amplitude spectrum of the backscattered return contains information on wave height and spatial spectrum, and the frequency spectrum of the return contains information on the velocity and height of the surface waves. The problem of extracting this information from the return and estimating the surface wave parameters needs yet to be pursued.

To produce an instrument that uses acoustic probes whose performance can be specified so that a physical scientist can be confident of the data it produces, a system of verified analytical models of this performance is required. Only in this way can performance bounds be tied to the physics of interaction in the acoustic probe and the environment and be differentiated from the physical parameters of the environment. To this end, a program of research in high-frequency underwater backscattering from volume scatterers is being pursued by the Acoustics Group at the Institute for Applied Research, Catholic University. This research is directed to supporting the system design of the use of LDE. Although many models of acoustic backscattering from individual scattering mechanisms have been developed, the real world involves weighed sums and convolutions of these mechanisms. The heart of the analytical problem that will cause acoustic probe technology to "come of age" is the ability to infer the environmental parameters of the individual scattering mechanisms from the combined effect or all of them on the acoustic probe. Again, for the scientist to be comfortable with this inference, it must be performed in a disciplined, analytical manner.

## CONCLUSIONS

The Chesapeake Bay, and the region of interest to preserve the ecological life of the region, offers a rich proving ground for recently developed remote sensing and probing techniques. Observations from sensors on orbiting platforms can be combined with measurements and profiles of environmental parameters obtained with *in situ* sensors and remote probes.

This type of network can combine the best of two worlds of technology in the solution of a pressing problem of environmental concern. With their large fields of view but questionable precision and atmospheric-induced instability in estimating environmental parameters, satellite observations can be continually calibrated in real time by ground-based sensors and probes. This ground truth can be obtained from observation platforms on the land around the Chesapeake Bay and on the surface and bottom of the Bay and its estuaries. The ground platforms could provide the necessary precision, stability, and resolution for the parameter estimates. In addition, the temporal and spatial frequencies of observations from the ground platforms need only be large enough to provide fiduciary data to complement satellite observations. High-resolution local profiles could also supplement the data obtained by satellite.

Integrated observation networks consisting of both satellite sensors and sensors and probes mounted on platforms at the surface of the Earth have application not only in the Chesapeake Bay region but also in other regions that may be ecologically threatened, such as the Delaware Bay or even the Gulf of Mexico. In the latter case, the physical expanse of the Gulf indicates that real-time acquisition of data from Earth-surface platforms could be performed most effectively through satellite communications links. These links would facilitate and motivate the use of a truly integrated data set from the observation network. Satellite communications networks would then provide the data base for real-time monitoring and predictive alarm to the sometimes distant centers of concern for environmental quality. The Chesapeake Bay could be used as the prototype for acquisition of such an integrated data set.

Atmospheric acoustic probes could be located either at shore stations near the Bay or on large surface buoys. At their respective locations, they could obtain vertical profiles of wind velocity and turbulence and the temperature and humidity of the atmosphere. At or near the buoy locations, underwater acoustic probes located on the bottom could be used to profile current velocity, density, and turbulence and also to determine tide level, wave height, spectrum, and direction. The physical parameter profiles at these Earth-surface stations could be used with surface observations by satellite. The most obvious use for data from this network is to verify and calibrate models of energy exchange between the water of the Bay and the atmosphere. Other applications of the data are extensive.

## REGIONAL ENERGETIC COUPLING OF MAN AND HIS ENVIRONMENT—DATA REQUIREMENTS\*

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### ABSTRACT

It is recognized that human and natural systems are coupled and can be interpreted, using a common base of energy-flow analysis. This analysis can be used to evaluate past, present, and future states of regional integrated systems in the coastal zone and to provide the capability for rational selection of alternative patterns of resource use. Energy flows (or flows of dollars or materials converted to energy equivalents) are believed to be the basic factor in the organizations of all types of systems. Therefore, if the energy basis of a system (Chesapeake Bay region) can be estimated quantitatively, alternatives can be selected that will tend to enhance the full value of that system (quality of life), as well as to permit comparisons with other systems of interest. An analysis example is provided of an estuarine subsystem of the Chesapeake Bay, and tabular listings of regional data needs are given. Current remote sensing capabilities are providing some of the necessary information. It is suggested that the energetic concept described here may provide remote sensing specialists with challenges for employment or development of new sensing devices.

### INTRODUCTION

One major objective of this paper is to emphasize a way of perceiving regional environmental systems. In effect, these ecosystems can be regarded as natural free-energy machines. We suggest that an energy analysis methodology can serve as a rational basis for evaluating alternative regional management/use schemes. A second major objective is to provide remote sensing specialists with a new conceptual framework for using available sensing capabilities

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\*Contribution No. 745, Center for Environmental and Estuarine Studies, University of Maryland.

or indeed, for them to recommend the development of new sensing tools that will make regional energetic analyses easier.

It is generally recognized that man's interaction with his environment has undergone considerable scaling changes in this century. Single decisions may have far greater environmental consequences than ever before. A fundamental task is to determine which of the many alternative patterns of resource use or interaction is the most rational or best alternative. Our past societal operating procedures have tended to use traditional economic benefit/cost analysis or a political/social solution to select an alternative. Critics of these two procedures have complained that benefit/cost analyses usually do not have a proper methodology for costing resource values. Similarly, the political/social solutions are vulnerable to so-called special-interest pressure or lobbying. Thus, how can a proper basis be determined for selecting alternatives to serve society's interest best and to enhance a "quality-of-life" concept for the Chesapeake Bay region?

It is becoming increasingly apparent that the quality of human systems is highly dependent on the resources and functioning of natural systems through various feedback loops. The need to account for the value of nature to man in planning and designing human systems is one of society's major tasks (Krutilla and Fischer, 1975, and Odum, 1977). Indeed one has only to contemplate engineering and construction costs of building a new Chesapeake Bay to begin to grasp the scale of cost-value of this natural bio-energy system. One possible management solution is to base an analysis approach upon the "wisdom" of natural laws. Such an approach would greatly enhance the ability of those in the political/social arena to make viable decisions. It is possible to use an energy flow as a system parameter coupling of man and nature as suggested by Odum (1977). We are endeavoring to long run a(n) Einsteinian general theory to guide us (Odum 1977, page 37) through concepts referred to the Darwin-Lotka Energy Law that may serve as the foundation for coupling man and nature on an energetic basis, a portion of which follows:

"Thus, whenever it is necessary to transform energy, the greatest amount of energy at the fastest possible rate will get out of the way into the drain (Odum and Pinkerton, 1965). Nature and human both use energy and stores as part of their operations and when power is desired, the rate of use is maximized by adjusting loads. . . . In the last century, during a period of biological selection of *natural selection*, and early in this century Lotka (1956) indicated that the maximization of power for useful purposes was also a trait of the natural selection. Darwin's evolutionary law thus developed into a general law of energy flow."

An increased awareness of our energy interactions with our ecosystems by an increasingly larger segment of the public, along with the need for a new dimension to be added to research data needs (Bennett, 1977) are impelling quantitative measurements on

\*Material in italics only.

natural populations and communities dealt with standing stock values—that is, the amount of material present in a unit area at any given time. Concerning pollution ecology studies or evaluation of environmental change problems, decisions were often based on changes in standing stocks of a target species or community over time. Many past remote sensing efforts have been aimed at measuring these standing stocks. However, we must not only be able to measure and compare stock changes, but also be able to answer questions on how the system is functioning under these changed-stock conditions. That is: 1) Is energy and material flow blocked?, or 2) If flow is not blocked, is it still moving in this altered state into a like quantity of useful biological material? Condition 1 is obviously biologically and socially unacceptable. Condition 2 may be both biologically and socially acceptable.

The area under consideration in this conference is the Chesapeake Bay region. We are therefore provided with a natural and defined ecosystem—one that has an identifiable phase boundary (watershed). Although this boundary might be considered artificial, it provides an enclosed area through which we can consider the import and export of energy and material. Similarly, within the Bay region, we can define subsystems such as the Patuxent Estuary, whereby we can describe energy and material flow within that system, as well as the flow in and out of that subsystem's boundaries.

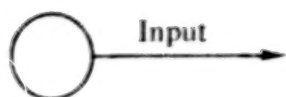
### **METHODOLOGIES USED FOR ENERGETIC ANALYSIS**

The general methodologies employed are those developed by Odum and his colleagues at the University of Florida (Odum, 1971; and Odum and Brown, 1975). Four major calculations will be discussed: energy value, energy-investment ratio, energy-cost/benefit ratio, and energy quality.

#### **Energy-Value Calculations**

Energy-value calculations are made to quantify total work contributions from all major components of urban and natural ecosystems in the study area. Energy flows (or flows of dollars or materials converted to energy equivalents) are believed to be a basic factor in the organization of all types of systems. Therefore, if the energy basis of a system is estimated quantitatively, alternatives can then be selected that tend to enhance the full value of that system, as well as to permit comparisons with other systems of interest.

In developing an energy-value calculation, the first step is to construct a model diagram for organizing data. Systems can be viewed at several scales for study. The hierarchical nature of a power-plant system in Florida is indicated in figure 1, with several subsystems within larger systems. Additional diagramming seeks to summarize all the work processes that contribute to the overall functioning of a region, including those of both man and nature. Energy-circuit language symbols such as those given in figures 2 and 3 may be used in constructing these diagrams. Symbol definitions (adapted from Young et al., 1974) are:



Forcing function—An outside source of energy or materials entering the system of interest.



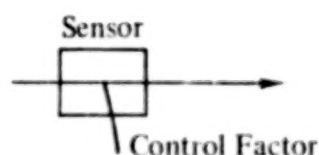
Pathway of energy or materials. Arrow indicates the direction of travel.



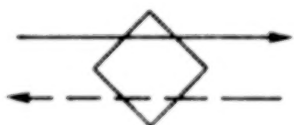
Adding junction—Intersection of two similar flows capable of adding.



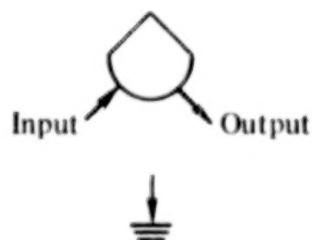
Pathway of money flow.



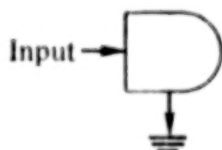
Rate sensor—Monitors flow rate of carrier and controls the input of a quantity in proportion to the flow of the carrier. Sensor can also be used for similar purposes with a storage.



Economic transaction—Flow of money is opposite to the flow of energy as in sales at a grocery store.



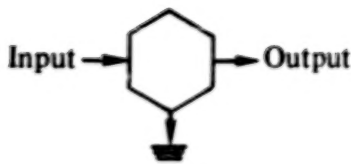
Passive storage—A storage of energy or materials within the system of interest.



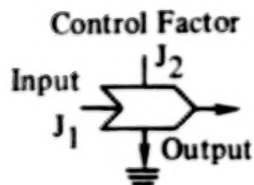
Heat sink—Indicates a loss of potential energy as a consequence of the second law of thermodynamics.

Green plant—Normally used to illustrate photosynthesis, but used in regional diagrams to represent an entire ecosystem.





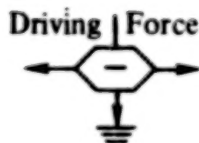
Self-Maintaining consumer—Combination of storage and workgate symbols whose response is autocatalytic (e.g., an animal, city, or industry).



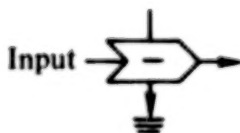
Workgate—Intersection at which one flow ( $J_2$ ) makes possible a second flow ( $J_1$ ).



Two-way workgate—The direction of flow is determined by a gradient, hydrostatic head, etc. and the rate is in proportion to the gradient times the driving force.



Two-way workgate—As in above, except that driving force inhibits the flow.



Workgate—Special case of the above in which the intersection has a retarding effect on the process.

All major pathways on the diagram are then evaluated in units of work/time (joules/area/time). Natural ecosystem work is evaluated using gross metabolism or productivity and respiration as an estimate of total work. Work done by physical activities, such as tidal and wind action, is evaluated using standard formulas. Work done in urban activities is often most easily available in dollars and can be converted to energy units using the method given in Odum and Brown (1975). When the energy diagram is fully evaluated a table is constructed with each pathway in the diagram becoming an entry in the table. Next, each entry is converted to a common type of energy flow using an energy quality ratio. Energy quality is discussed later in this section. When all entries are converted, they may be summed, giving a quantitative index of value generated in the study region per year.

### Energy-Investment Ratio

Information generated in the energy-value calculation can be used to calculate an energy-investment ratio. The energy-investment ratio is the ratio of energies purchased from outside the system to the natural energies operating in the study area. The purchased energies



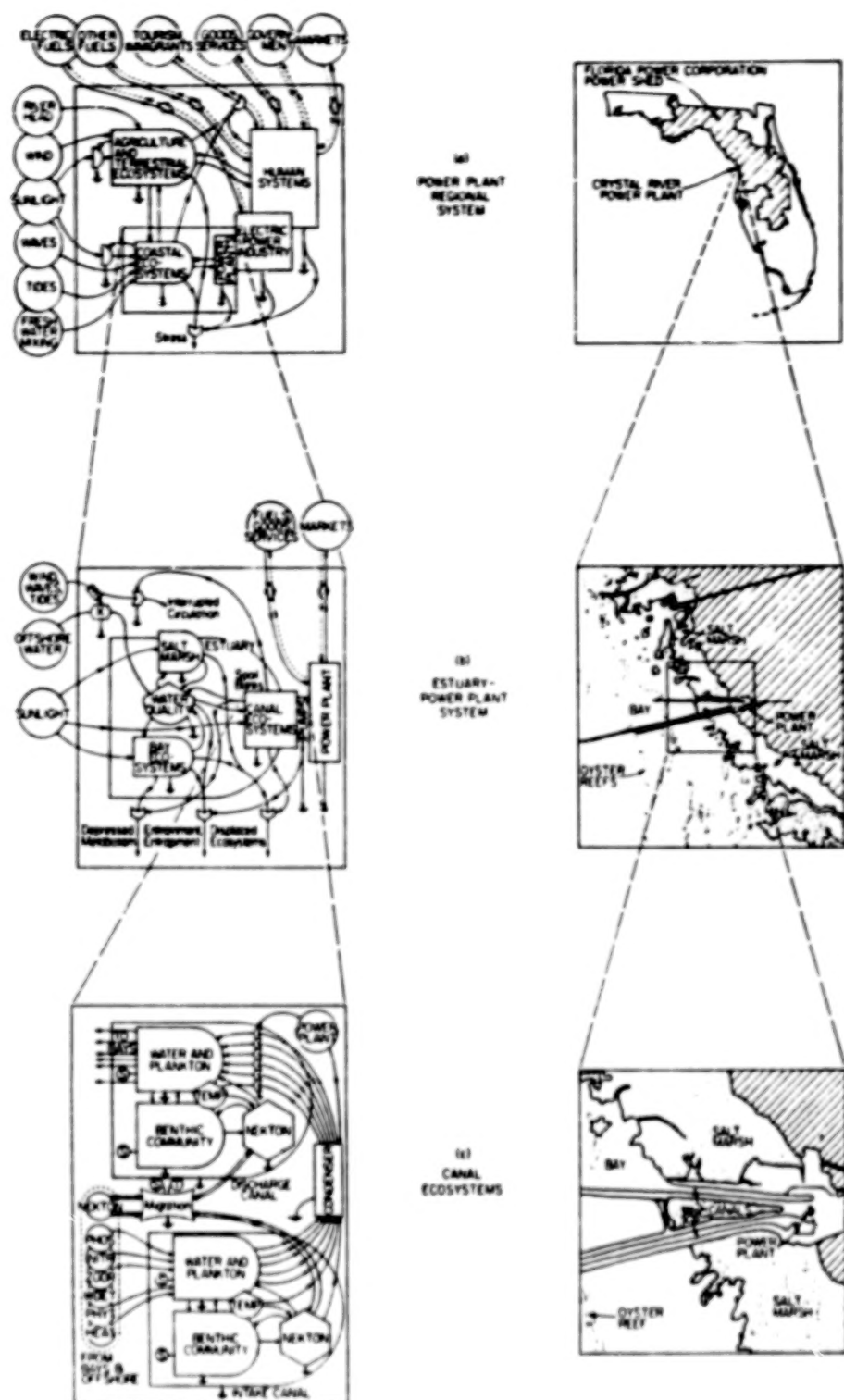


Figure 1. Energy diagrams and maps of the Crystal River power region showing the three hierarchical scales studied. For explanation of symbols, see Odum (1971).

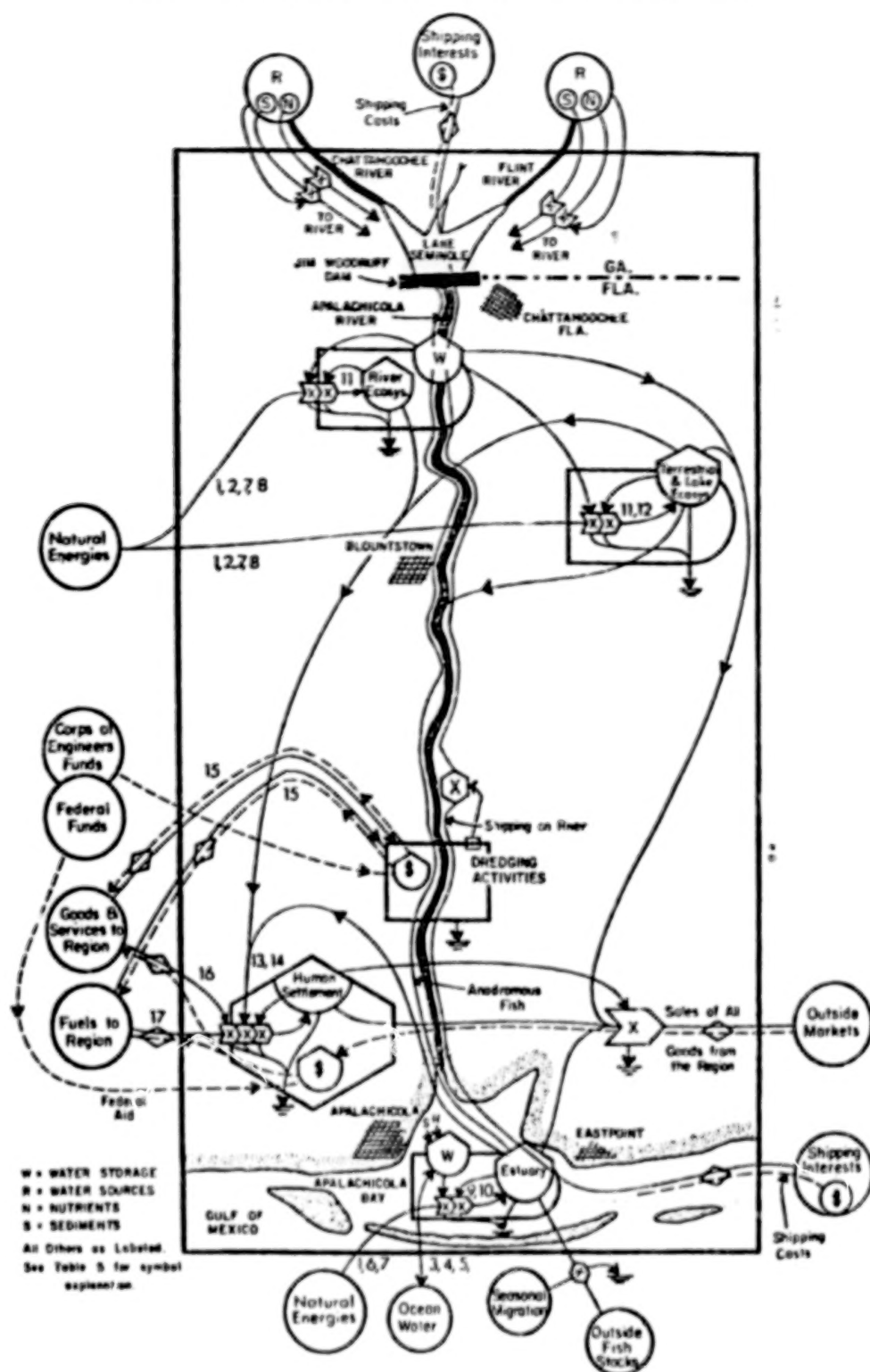


Figure 2. Simplified energy model of the Florida portion of the Apalachicola River Basin.

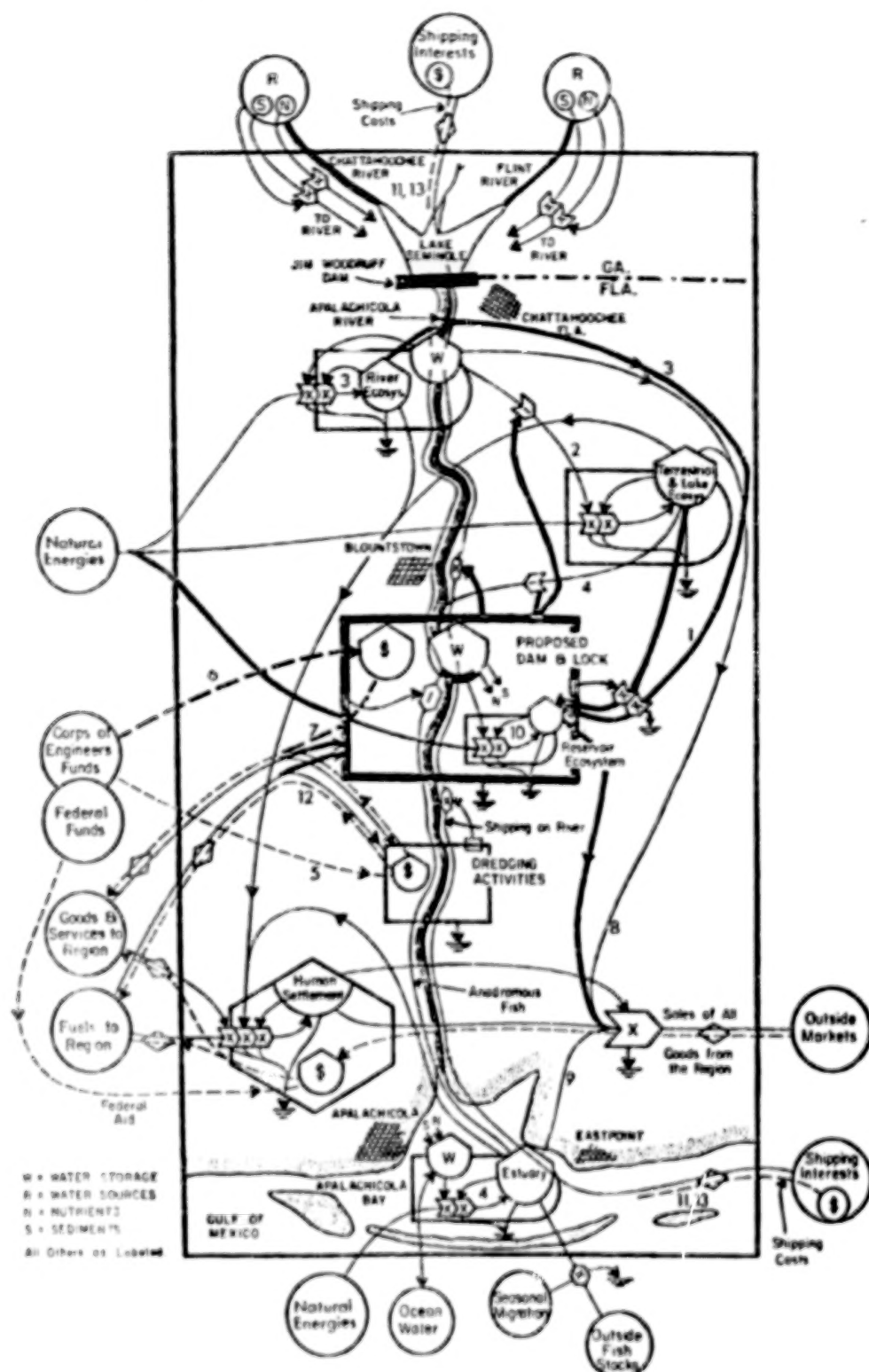


Figure 3. Simplified energy model of the Florida portion of the Apalachicola River Basin. Bold lines show proposed navigation dam and new pathways.

are generally goods, fuels, and services and are usually of higher quality than resident natural energies. In 1973, this ratio (figure 4) was estimated to be 2.5 to 1 for the United States (Odum and Brown, 1975). Systems that have a relatively low investment ratio can match high-quality external energies with more low-quality natural energies and can therefore compete well with the products offered for exchange. This concept suggests that, as the local investment ratio exceeds the ratio of surrounding systems, the local system generates less value per unit of high-quality energy used. This decline in value per unit could be reflected in higher prices required for exports and would therefore be a disadvantage in competing with other less-developed systems for high-quality energies. The ultimate contribution of energy flows depends on both high-quality purchased flows of fossil fuels and resident natural energies with which the high-quality flows interact.

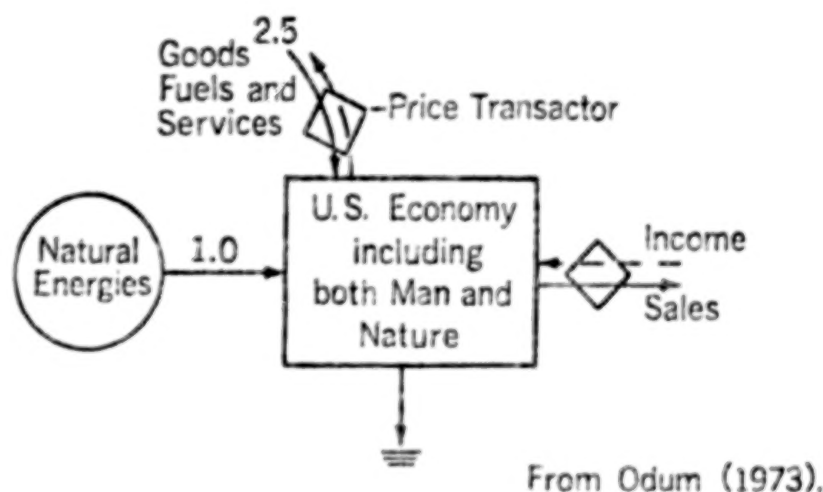


Figure 4. Simplified energy model showing estimated balance of input energies to the U.S. economy (from Odum, 1973). The 1973 investment ratio from the figure is 2.5 (2.5:1).

In this analysis, the energy-value calculation of the present regional pattern is done to characterize the balance of purchased and natural energies in the study area. These data are used to generate the investment ratio that indicates the desirability of adding more development to a region or in some other way altering the pattern or extent of natural resource use by man.

#### Energy Cost/Benefit Calculation

This calculation is similar to the energy-value calculation in that a diagrammatic model is constructed and evaluated, and pathways on the model are entered into a table for energy-quality adjustment and tabulation. The main difference is that this calculation is focused on changes in energy-flow pathways that could result if a proposed alternative is developed. The criteria for selection of an alternative requires that the alternative generate as much value as

is required for its own development and maintenance. This calculation is somewhat similar to traditional cost/benefit calculations in that changes are considered. However, it differs in that environmental as well as financial changes are explicitly evaluated. It also differs in that all changes are first adjusted to the same energy-quality level before comparisons are made.

### Energy Quality

The value of a system process is defined as the contribution of the process to the useful work of the system. However, raw energy flows, as measured in joules (kcal) of heat, do not represent the ability to do work but rather show only the heat content of that particular flow. Whereas any energy flow can be degraded to heat with 100-percent efficiency, the ability of an energy flow to do useful work depends on the packaging or concentration of that flow. For instance, the joules (J) associated with wood production in photosynthesis represent the concentration to wood joules of the dilute of unprocessed sunlight. In the same way, electrical energy is at higher concentration than the energy contained in coal; its generation requires approximately 16.7 kJ (4 kcal) of coal-type energy to obtain one unit of electrical-type energy. The coal contributes 12.6 kJ (3 kcal) of coal energy to operate steam engines and one kilocalorie is expended to perform the work of constructing and maintaining the power-plant structure. Several other examples of conversion calculations were given by Odum et al. (1974) for relating kilocalories (joules) of wind, wood, and electricity. Energy-quality factors relating producers and many consumers in a shallow marine ecosystem were given by McKellar (1975). Thus, the foregoing considerations suggest ways to compare varying types of energy flows in macroscopic systems of man and nature. Before comparisons are made, each flow must be converted to a common baseline energy quality. In this paper, all energy flows have been converted to the fossil-fuel quality level (expressed as  $\text{kcal}_{\text{FFE}}$ ).<sup>\*</sup> A list of conversion factors was given by Boynton (1975).

Kemp and Boynton (1976) recently described examples of the kinds of data required for an energetic analysis. These data, reproduced in table 1, were used in evaluating the conceptual model illustrated in figure 3 for the Apalachicola River Basin in Florida. The values shown in table 1 represent the final outcome of collected scientific data. Examples of the types of calculations used in developing the data are given in the footnotes to table 1.

### DISCUSSION

A pilot study using the foregoing energy-analysis approach was conducted in the Patuxent Watershed of the Chesapeake Bay system in 1976.<sup>†</sup> The purpose of the study was to develop a preliminary assessment of the feasibility and utility of using a portion of the Chesapeake system for analyzing energy flow and to gain an understanding of the natural and purchased

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<sup>\*</sup>Calorie = 4.184 Joule.

<sup>†</sup>Geri Unger, "A Regional Fingerprint, Patuxent Watershed, Maryland," University of Maryland, Chesapeake Biological Laboratory, 1976, unpublished manuscript.

Table 1  
Energy-Value Calculations for Six-County Region<sup>a</sup>

Pathway on Figure 2	Name of Energy Flow	Area of System (acres) <sup>b</sup>	Annual Work Per Acre (10 <sup>7</sup> kcal/acre/yr) <sup>c</sup>	Total Annual Work 10 <sup>12</sup> kcal/yr <sup>d</sup>	Energy-Quality Factor (Boynton, 1975)	Annual Work in Fossil-Fuel Equivalents (10 <sup>12</sup> kcal <sub>FF</sub> /yr) <sup>e</sup>
Contributing Natural Energy Flows						
1	Total sunlight	3,256,742	591.0 <sup>f</sup>	19,300.0	2,000	9.63
2	Heat gradient	3,256,742	4.10 <sup>g</sup>	134.0	10,000	0.01
3	Estuary tides	127,020	0.15 <sup>h</sup>	0.19	2.5	0.08
4	Shoreline waves	—	0.06 <sup>i</sup>	0.068	5.0	0.01
5	Mixing energy (ΔF)	—	—	0.256 <sup>i</sup>	0.3	0.85
6	Hydrostatic head	—	—	0.23 <sup>i</sup>	0.63	0.37
7	Wind	3,256,742	—	8.21 <sup>j</sup>	7.7	1.06
8	Rain	—	—	—	—	—
	Mixing energy (ΔF)	2,643,000	—	~0 <sup>k</sup>	0.3	0.0
Metabolic Energy Flows in Natural Systems						
9	Coastal plankton system	406,400	1.33 <sup>k</sup>	5.41	20	0.27
10	Estuarine systems	149,853	4.90 <sup>k</sup>	7.34	20	0.37
11	Freshwater systems	56,600	11.20 <sup>j</sup>	6.34	20	0.32
12	Terrestrial systems	1,873,000	4.83 <sup>m</sup>	90.5	20	4.53
						5.49
Metabolic Energy Flows in Managed Ecosystems						
13	Agriculture	630,000	4.9 <sup>n</sup>	30.9	20	1.55
14	Urban vegetation	33,600	1.2 <sup>o</sup>	0.4	20	0.02
						1.57

Table 1 (Continued)

Pathway on Figure 2	Name of Energy Flow	Area of System (acres) <sup>b</sup>	Annual Work Per Acre (10 <sup>7</sup> kcal/acre/yr) <sup>c</sup>	Total Annual Work 10 <sup>12</sup> kcal/yr <sup>d</sup>	Energy-Quality Factor (Boynton, 1975)	Annual Work in Fossil-Fuel Equivalents (10 <sup>12</sup> kcal <sub>FFE</sub> /yr) <sup>e</sup>
Energy Flows in Urban Systems						
15	Expenditures for dredging	—	—	0.02 <sup>p</sup>	1.0	0.02
16	Goods and services	—	—	5.16 <sup>q</sup>	1.0	5.16
17	Fuels	—	—	—	—	—
	Gasoline	—	—	1.74 <sup>r</sup>	1.0	1.74
	Kerosene	—	—	0.03	1.0	0.03
	Bottled gas	—	—	0.07	1.0	0.07
	Electricity	—	—	0.73	0.28	2.61
						9.63

Notes:

$$^a \text{Total energy flow} = 19.05 \times 10^{12} \text{ kcal}_{\text{FFE}}/\text{yr}$$

$$\text{Investment ratio} = \frac{\text{Purchased goods, fuels, and services}}{\text{Natural energy flows}} = \frac{9.63 \times 10^{12} \text{ kcal}_{\text{FFE}}/\text{yr}}{9.42 \times 10^{12} \text{ kcal}_{\text{FFE}}/\text{yr}} = 1.02$$

$$^b \text{Acres} \times 4,047 = \text{km}^2$$

$$^c \text{Calorie} = 4.142 \text{ Joule}$$

$$^d \text{Calorie} = 4.142 \text{ Joule}$$

$$^e \text{Calorie} = 4.142 \text{ Joule}$$

<sup>f</sup>Total sunlight was estimated by multiplying average yearly sunlight by total area. Average sunlight input was estimated to  $4 \times 10^3 \text{ kcal/m}^2/\text{day}$  (Odum, 1971). Total area included all land and water areas in the six-county region plus estuarine and coastal areas.

$$(4.0 \times 10^3 \text{ kcal/m}^2/\text{day}) (3.26 \times 10^6 \text{ acres}) (4,047 \times 10^3 \text{ m}^2/\text{acre}) \times (365 \text{ days/yr}) = 1.93 \times 10^{16} \text{ kcal/yr}$$

<sup>g</sup>Local heat gradient work was estimated by multiplying average sunlight input per area per year times a Carnot ratio ( $\Delta T = 2 \text{ K}$ ) times the total study area (Odum et al., 1974).

$$(4000 \text{ kcal/m}^2/\text{day}) \frac{2}{288.5} (365 \text{ days/yr}) (4,047 \text{ m}^2/\text{acre}) (3.26 \times 10^6 \text{ acres}) = 1.34 \times 10^{14} \text{ kcal/yr}$$

Table 1 (Continued)

## Notes (continued):

<sup>h</sup>Annual work done by rain was divided into three categories. The work done in photosynthesis was accounted for in terrestrial and fresh water system metabolism measurements and was not recounted here. The potential energy of water (from rain) because of its position relative to sea level was included in the calculation of hydrostatic head of river water and was not recounted here although some head water is lost as local land areas drain into the river. The potential energy of rain water relative to river water attributable to the concentration differences (mixing energy) was calculated using runoff. Concentration changes were from 1.2 ppm (rain) to 120 ppm (river water). Mixing energy per gram of solute was calculated to be 326 joules (78 cal). The total runoff flow was estimated to be 43 cm/yr.

$$\text{Total flow/yr} = (43 \text{ cm/yr}) (1.07 \times 10^{14} \text{ cm}^2) = 4.6 \times 10^9 \text{ m}^3/\text{area/yr}$$

$$(78 \text{ cal/g solute}) (1.29 \text{ g/m}^3) (4.6 \times 10^9 \text{ m}^3/\text{area/yr}) (10^{-3} \text{ kcal/cal}) = 4.31 \times 10^8 \text{ kcal/yr}$$

<sup>i</sup>Estimates of the work done by tides in the estuary—waves on the shoreline, mixing energy, and hydrostatic head—were defined and calculated as given in Boynton (1975). The hydrostatic head calculation was adjusted to reflect the elevation change between Apalachicola Bay and Jim Woodruff dam ( $\Delta 13.4 \text{ m}$ ).

<sup>j</sup>The yearly work done by winds was based on the kinetic energy of the wind. An eddy diffusion coefficient of  $1 \times 10^4 \text{ cm}^2/\text{s}$  was used. Average wind velocity was estimated to be 14 kmph (8.7 mph) (University of Florida, 1973). This wind speed was assumed to occur 10 m above the ground. Total area for the six-county region was  $1.32 \times 10^{14} \text{ cm}^2$  ( $3.26 \times 10^6 \text{ acres}$ ).

$$(1.2 \times 10^{-3} \text{ g/cm}^3) (371 \text{ cm/s})^2 (1 \times 10^4 \text{ cm}^2/\text{s}) (2.39 \times 10^{-11} \text{ kcal/erg}) \times (3.15 \times 10^7 \text{ s/yr}) (1.32 \times 10^{14} \text{ cm}^2) = \\ (2) (1 \times 10^4 \text{ cm}) 8.21 \times 10^{12} \text{ kcal/yr}$$

<sup>k</sup>Metabolism of the coastal plankton system and estuarine systems was estimated as given in Boynton (1975).

<sup>l</sup>The area of freshwater systems included all lakes and rivers in six-county study area (University of Florida, 1973). Metabolism was estimated to be about  $11 \times 10^7 \text{ kcal/acre/yr}$  (Odum, 1971).

$$(11 \times 10^7 \text{ kcal/acre/yr}) (5.66 \times 10^4 \text{ acres}) = 6.34 \times 10^{12} \text{ kcal/yr}$$

<sup>m</sup>Metabolism of terrestrial systems was estimated as given in Boynton (1975). The area of terrestrial systems was adjusted to cover the six-county area (Florida Statistical Abstract, 1973).

$$(5.68 \times 10^7 \text{ kcal/acre/yr}) (2.64 \times 10^6 \text{ acres}) = 150.0 \times 10^{17} \text{ kcal/yr}$$

<sup>n</sup>Work done by metabolism of agricultural crops. Agricultural area was  $2.55 \times 10^9 \text{ m}^2$  (University of Florida, 1973). Agricultural crop metabolism was estimated to be  $4.9 \times 10^7 \text{ kcal/acre/yr}$  (Odum and Brown, 1975).

$$(6.3 \times 10^5 \text{ acres}) (4.9 \times 10^7 \text{ kcal/acre/yr}) = 30.9 \times 10^{12} \text{ kcal/yr}$$



Table 1 (Concluded)

## Notes (Concluded):

<sup>o</sup>Work done by urban vegetation was estimated by using a metabolism of  $1.2 \times 10^7$  kcal/acre/yr (Bayley and Odum, 1973) and an area of 135,979 km<sup>2</sup> (33,600 acres) (University of Florida, 1973).

$$(1.2 \times 10^7 \text{ kcal/acre/yr}) (33,600 \text{ acres}) = 4.0 \times 10^{11} \text{ kcal/yr}$$

<sup>p</sup>Current dredging expenditures were estimated to be \$8000,000/yr (Department of the Army, 1974).

<sup>q</sup>Energy equivalent of goods and services was estimated to be  $5.16 \times 10^{12}$  kcal/yr (University of Florida, 1973).

<sup>r</sup>Total fuel use obtained from Energy Data Center, Florida Dept. of Administration (1974):

$$\text{Gasoline} = 17.41 \times 10^{11} \text{ kcal/yr}$$

$$\text{Kerosene} = 3.21 \times 10^{10} \text{ kcal/yr}$$

$$\text{Bottled gas} = 6.54 \times 10^{10} \text{ kcal/yr}$$

$$\text{Electricity} = 7.30 \times 10^{11} \text{ kcal/yr}$$

energy ratios in the Patuxent basin. Table 2 lists the calculated values of internal energy flows for the watershed. Watershed characteristics used for calculations are as follows:

<u>Description</u>	<u>Numerical value</u>
Area of basin	2330 km <sup>2</sup>
Area of cropland	363.2 km <sup>2</sup>
Area of pastureland/bare fields	465.9 km <sup>2</sup>
Area of marshes	24.9 km <sup>2</sup>
Area of forests	925.7 km <sup>2</sup>
Area of water systems	126.4 km <sup>2</sup>
Area of urban systems	14.3 km <sup>2</sup>
Area of residential systems	335.7 km <sup>2</sup>
Areas of highly reflected surfaces (asphalt, cement)	9.2 km <sup>2</sup>
Average sunlight in basin area	1.25 × 10 <sup>16</sup> kJ/yr (3.01 × 10 <sup>15</sup> kcal/yr)
Length of the watershed	175 km (110 miles)
Tidal length of river	80 km
Width of river	~0 to 3.2 km (0 to 2 miles)
Average discharge of river at mouth	26.7 m <sup>3</sup> /s (943 ft <sup>3</sup> /s)
Average discharge of river above tidal influence	7.02 m <sup>3</sup> /s (248 ft <sup>3</sup> /s)
Average yearly rainfall	111.25 cm (43.8 in.)
Volume of reservoirs	50.7 billion liters (13.4 billion gal)
Yield of reservoirs	40 to 50 mgd (151 to 189 ml per day)
Area of reservoirs	6475 km <sup>2</sup> (1600 acres)
Number of people serviced by reservoirs	1.3 million
Total volume of sewage discharge	151.4 million liters (40 million gal) daily (62 cfs)
Average wind velocity	14.64 kmph (9.1 mph)
Average tidal amplitude	1.3 meters
Highest elevation of river	Approximately 79.2 meters (above sea level)
Number of sewage treatment plants	54
Population lower watershed, 1975 (St. Mary's, Charles, and Calvert Counties)	34,005
Population upper watershed, 1975 (Prince George's, Montgomery, Anne Arundel, and Howard Counties)	589,537
Total population in watershed	623,542
Total births/yr (lower watershed)	629
Total births/yr (upper watershed)	55,054
Total births/yr (watershed)	56,736

<u>Description</u>	<u>Numerical value</u>
Total deaths/yr (lower watershed)	250
Total deaths/yr (upper watershed)	9,662
Total deaths/yr (watershed)	9,912
Bushels of oysters caught (1975)	3439 m <sup>3</sup> (97,591 bushels)
Fish caught (1974)	12.5 mg (276,347 lb)
Lumber harvested in watershed	50,476 m <sup>3</sup> (21,388 × 10 <sup>3</sup> bd ft)
Lumber harvested in lower watershed (all species)	25,309 m <sup>3</sup> (10,724 × 10 <sup>3</sup> bd ft)
Lumber harvested in upper watershed (all species)	25,167 m <sup>3</sup> (10,664 × 10 <sup>3</sup> bd ft)
Stump price of lumber in watershed	1,069,000 dollars
Mill price of lumber in watershed	3,208,200 dollars
Economic value of crops in watershed (1975)	
Tobacco	16,264,000
Hay	1,989,000
Wheat	676,000
Barley	281,000
Corn	5,688,000
Soybeans	669,000
Total	25,567,000 dollars
Fertilizer use in basin	21,370 metric tons (23,556 tons)
Costs of applied fertilizer	2,708,940 dollars
Estimated total runoff for urban areas	2242 metric tons N/yr 1201 metric tons P/yr
Estimated total runoff for pasturelands	1008 metric tons N/yr 312 metric tons P/yr
Estimated total runoff for cultivated croplands	972 metric tons N/yr 186 metric tons P/yr
Total phosphorus from treatment plants	571.5 metric tons/yr
Total nitrogen from treatment plants	458 metric tons/yr
Total phosphorus from marshes	4.9 metric tons/yr
Total nitrogen from marshes	31.8 metric tons/yr

In summary, the pilot study was modestly successful in using a wide variety of data for describing the energetics of the Patuxent Watershed machine. Table 3 lists the results of an assessment of current conditions within the system. The macroscopic perception provided revealed an upper basin dominated by an urban purchased-energy system and a lower basin dominated by a natural-energy system of agriculture and water-related resources. Continued

Table 2  
Values of Natural Internal Energy Flows (Gross Primary Production)  
of the Patuxent Watershed Study Area

Name of Flow	Area of System km <sup>2</sup>	Total Annual Work Per Unit Area 10 <sup>11</sup> kcal/yr*	Energy Quality Factor	Total Annual Work 10 <sup>11</sup> kcal <sub>111</sub> /yr*
River ecosystem	31.4 km <sup>2</sup>	1.10	20	0.050
Reservoir system	6.5 km <sup>2</sup>	0.19	20	0.009
Forest ecosystem	926 km <sup>2</sup>	74.00	20	3.70
Urban system	359 km <sup>2</sup>	9.20	20	0.46
Agricultural system	829 km <sup>2</sup>	55.00	20	2.80
Marsh ecosystem	25 km <sup>2</sup>	1.10	20	0.05
Estuarine ecosystem	88.5 km <sup>2</sup>	4.60	20	0.23

\*Calorie = 4.142 Joule.

Table 3  
Comparison of Upper Patuxent Watershed to  
Lower Patuxent Watershed (1973)

Parameter	Upper Patuxent (Howard, Anne Arundel, Montgomery, and Prince George's)	Lower Patuxent (Calvert, St. Mary's, and Charles)
Population (1973)	581,580 people	32,040 people
Area in basin	1736 km <sup>2</sup>	592 km <sup>2</sup>
Income into basin from manufactured goods (1973)	559.9 × 10 <sup>6</sup> dollars/yr	13.4 × 10 <sup>6</sup> dollars/yr
Income in dollars/km <sup>2</sup> /yr	32 × 10 <sup>4</sup> dollars/km <sup>2</sup> /yr	2.3 × 10 <sup>4</sup> dollars/km <sup>2</sup> /yr
Export of dollars from basin (1973)	1737.8 × 10 <sup>6</sup> dollars/yr	60.0 × 10 <sup>6</sup> dollars/yr
Kcal <sub>111</sub> * entering the basin (1973)	43.4 × 10 <sup>12</sup> kcal <sub>111</sub> /yr	1.5 × 10 <sup>12</sup> kcal <sub>111</sub> /yr

\*Calorie = 4.142 Joule.

urban development of the upper basin may threaten the lower natural-energy system because of the transport of waste residuals from the upper basin to the lower system by the Patuxent River/Estuary.

We believe that the previously discussed Patuxent Study demonstrates the possibility of perceiving an ecosystem as an energy machine. What is still required is an evaluation of various future use strategies. This evaluation can be made for this subbasin and for the entire Chesapeake region. Remote sensing techniques can provide quick regional information to assist in rapid assessment of current and future alternatives.

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## RELATIONSHIP OF LAND USE TO WATER QUALITY IN THE CHESAPEAKE BAY REGION

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### ABSTRACT

Land use on the drainage basins of the Chesapeake Bay strongly affects the composition of runoff waters and, thereby, the water quality of the Chesapeake Bay. Both the proportions of the various land-use categories present on each watershed and the specific management practices in use on each category affect the quality of runoff waters. This phenomenon is usually categorized as nonpoint or diffuse-source pollution. In 1973, the Smithsonian Institution initiated a research program designed to quantitate and to better understand diffuse source pollution in the Chesapeake region. Grants from the National Science Foundation/Research Applied to National Needs Program and the Environmental Protection Agency to the Chesapeake Research Consortium and the Smithsonian Institution have supported this program. A series of small watersheds on the Rhode River (an arm of the Chesapeake Bay just south of Annapolis, Maryland) have been permanently instrumented to measure water discharge rates and to take volume-integrated water samples. Several portable stations are also operating on the Patuxent River. They will be moved frequently from basin to basin to collect data on seasonal discharges. Several permanent stations are being constructed on subbasins of the Choptank River at the Horn Point research center of the Center for Estuarine and Environmental Studies. These stations are operated by a team of scientists under the local direction of Dr. John Stevenson. All stations are designed to collect volume-integrated samples. All samples are analyzed for a series of nutrient, particulate, bacterial, herbicide, and heavy metal parameters. Each basin is mapped in detail with respect to land use by the analysis of low-elevation aerial photos. These analyses are verified and adjusted by direct ground-truth surveys. All data are processed and stored in the Smithsonian Institution computer data bank. Average seasonal area-yield loadings from each land-use category for each parameter are then calculated. Land-use categories being

investigated include forest/old fields, pastureland, row crops, residential areas, upland swamps, and tidal marshes. These data are useful in determining year-to-year variations in diffuse source loading because of weather variations and area-to-area differences attributable to topographic and geological differences and in predicting long-term changes in diffuse-source loading caused by urbanization or other land-use shifts in a given area. Other studies are directed toward mechanistic watershed model development and the determination of the effects of altered land-use practices (e.g., the use of minimum-till or no-till practices in corn production). In these studies, intensive data are collected concerning land-use practices, weather, soil chemistry and physics, and vegetation.

## INTRODUCTION

The way we use our lands strongly affects the quality of runoff waters and, thereby, the water quality of the receiving waters. Thus, well-vegetated areas will have lower erosion rates than those with bare soils, areas with a great deal of impervious surface will discharge rainfall much more rapidly and completely, and swamps will trap large amounts of particulates in runoff waters as they move through the swamps. In general, we can describe land use in terms of categories such as row crops, residential, and forest or in terms of land-use practices that prevail on a given land-use category. For example, contour plowing, strip cropping, or no-till practices on the row-crops category. The water quality effects of most common concern are flooding, erosion and siltation, nutrient eutrophication, contamination with pathogens, and contamination with toxic substances such as heavy metals and pesticides. These effects on water quality are usually called nonpoint or diffuse-source pollution. In order to study these effects of land use, the natural spatial unit is the watershed, and it is very important to be able to accurately analyze and map the land use of each watershed. This land-use analysis can be done by direct ground survey of each land parcel for very small areas, but, for studies of larger areas, remote sensing methods are necessary. This paper deals with a non-point source research program on the Chesapeake Bay and some of the results and problems that have been encountered in analyzing the land use on the various basins studied.

## METHODS

### Description of Watershed

Figure 1 shows the geography of the Rhode River watershed and the various subwatersheds that are under study, as well as the location of the weather station (W) and rain gages (R). The monitored watersheds vary in size from a few to about 1200 hectares (ha). Land use varies from all or nearly all one type to complex mixtures of all land-use categories. The larger basins include some (102,108) with relatively high proportions of row crops, one (121)

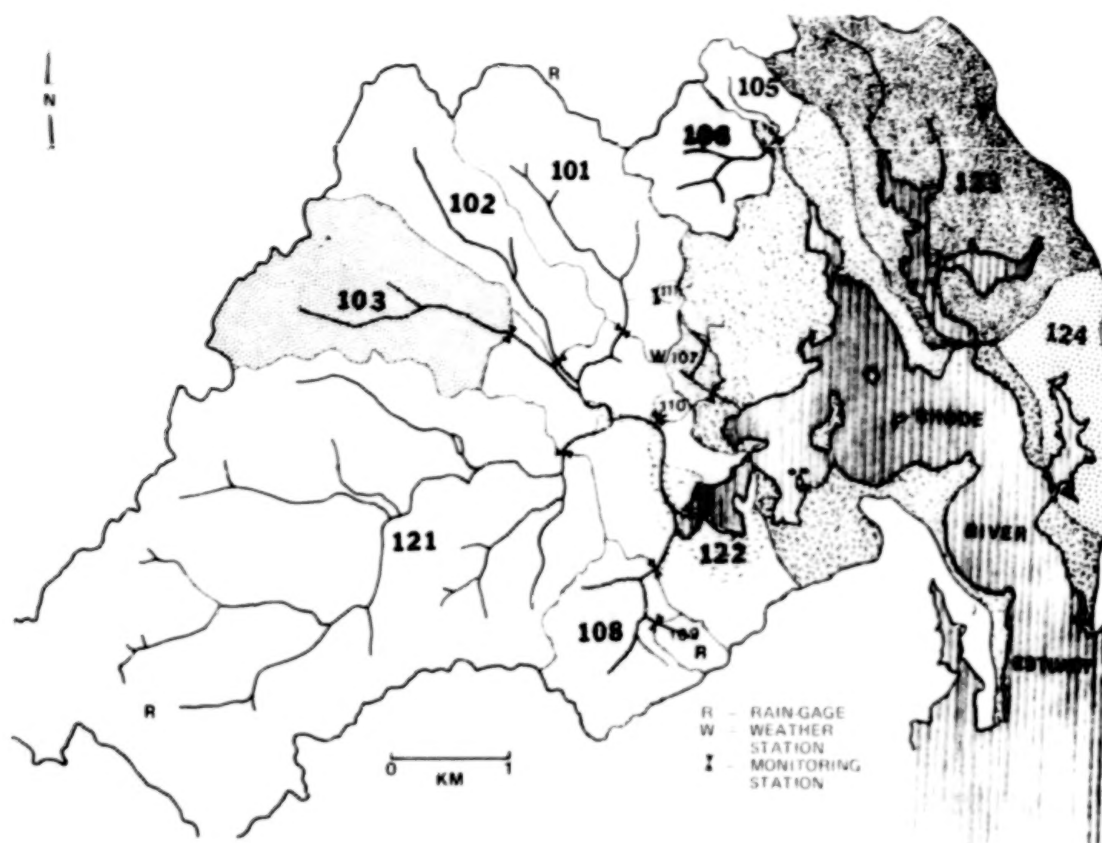


Figure 1. Rhode River drainage basins.

with more upland wet areas, one (122) with more tidal wet areas, many (103, 105, 107, and 122) with high proportions of forest and old fields, some (101 and 106) with more pasture, and two (123 and 124) with more residential area. Small single-use watersheds (109, 110, and 111) have been selected for intensive study of areas that best typify row crops, forest, and pasture land uses. The slopes of the larger watersheds average between 3 and 9 percent, with an overall average slope for the entire study area of about 5 percent.

#### Design and Instrumentation of Monitoring Stations

All V-notch weirs (stations 101, 102, 103, 105, 106, 107, 108, 109, 110, and 111 in figure 1 and the portable stations on the Patuxent River) are now 120° sharp, crested V-notch weirs. Correll, Pierce, and Faust (1975) described the instrumentation of these weirs. It has now been improved to include two parallel sampling pumps, one of which pumps to a glass sample bottle, the other to a plastic sample bottle that initially contains a small volume of 18 N sulfuric acid. In some cases on very small watersheds, the normal 25-lobe sampling cam in the Leupold and Stevens Model 61 R flowmeter has been replaced by a 50-lobe cam. Custom fraction collectors have been built for use on some weirs, especially on small, single-use

watersheds. These fraction collectors are designed to trigger automatically at a predetermined water stage. They then collect a fixed aliquot of water each time the flowmeter sampling switch is triggered (giving a pulse) by a given volume of flow. A pulse counter triggers the fraction collector to move from one bottle to the next when the preset number of pulses have been received. An event marker on the flowmeter stripchart records the times of fraction-collector movement. Twelve bottles of 12 liters volume each can be collected. Because the fractions are collected at identical times to the volume-integrated composite samples, the composition of flows, both before and after storm event flows, can be calculated.

The instrumentation of the completed flux-section monitoring stations (121 and 122 in figure 1) is complicated by the movement of tidal currents at these locations. These tides would submerge and, at times, reverse the flow in any conventional weirs or flumes. Therefore, these stations were instrumented with electromagnetic current meters (Marsh-McBirney Model 711) and tide gages (Leupold and Stevens Model F), interfaced electronically to volume-integrating water samplers. Although the sampler pumps through a solenoid valve that is normally connected to one sample bottle, when current reverses because of tides, it is activated and shunts the water to another bottle. The water-current sensor is kept positioned at the midpoint of the flux-section water column by a mechanical linkage to the tide gage. The analog voltage output from the current meter passes through a linear 10-kohm slide-pot potentiometer that is controlled by a custom-designed cam on the tide gage to correct current velocity for cross-sectional area. This modulated signal is "integrated" for 30-minute intervals by reading into a coulometer. The accumulated charge is read out every 0.5 hour at a constant wattage, and the sampling pump runs while it reads out. Two coulometer circuits alternate each time period. Thus, this system pumps for a variable time every 0.5 hour, in contrast to the V-notch weirs, which pump for a constant time each flow interval. The voltage from the flowmeter is positive for downstream currents and negative for upstream currents. A voltage sensor controls the sampling solenoid valve. A variable resistance on the coulometer readout circuit provides variable sampling sensitivity, and a standard calibration read in voltage permits standardization. The sensor for the current meters is located at a different lateral position in these flux sections. At station 121, a 4.8-meter wide concrete tidal flume was constructed, and the probe was centered. Fluorescent-dye dilution tests indicated that this point (that of maximum velocity) was nearly two times the average current velocity under a series of different tidal and flow conditions. The other station (122) is a neck at the downstream end of the sediment trap in the estuary before the dropoff into deeper water. This is 165 meters wide, and the point of average current velocity laterally was determined by calculating manual tidal current and tidal cross-section measurements under various tidal conditions. All stations are entirely battery operated and are usually serviced twice a week. Volume-integrated samples are collected weekly.

The monitoring stations on the Choptank River include three Parshall flumes instrumented in a manner similar to the weirs at Rhode River. However, these are expected to collect only surface runoff. Because of the very flat topography in that area, ground-water percolation



emerges directly into the estuary. A network of ground-water wells has therefore been established to monitor ground-water quality and the slope of the water table. A tidal flux section identical in design to station 121 at Rhode River is also being instrumented.

#### **Parameters Measured on Runoff Waters**

Rainwater and stream water samples are now analyzed for: pH, turbidity, temperature, total and orthophosphate phosphorus in filtered and whole water, total Kjeldahl nitrogen, nitrate, nitrite, ammonia, organic matter, alkalinity, total and mineral suspended particulates, suspended particle mineralogy, eleven cations (Ca, Mg, K, Fe, Ni, Cu, Zn, Pb, Cr, Cd, and Mn), total viable bacterial cells, total and fecal coliform bacteria, fecal streptococci, and six herbicides (alachlor, atrazine, simazine, linuron, trifluralin, and paraquat).

#### **Land-Use Analysis**

Aerial photography was taken with a 70-mm Hasselblad space camera with a wide-angle lens from a Cessna 180 flying at an elevation of 1800 m. One set of photos was taken on March 20, 1976, with infrared aerochrome 2443 film, and one set was taken on May 28, 1976, with positive color aerochrome 2448 film. These photos were projected over a base map with 60-cm (2-ft) topographic contours and a scale of 60 m = 2.54 cm (200 ft = 1 in.) with a Bausch and Lomb model ZT4 zoom-transfer scope. This permitted us to correct for distortion. A land-use overlay was then prepared. Areas of land-use parcels were then determined with a Hewlett-Packard model 9864A digitizer and a Hewlett-Packard model 9810A programmable calculator. Digitized map data (base map, stream channels, roads, shorelines, and topographic information) were also stored on magnetic tape for further analysis and graphics. This digitizing was done on a Calmagraphic III system that incorporates a Data General Nova 1200 data processor. This equipment is owned by the U.S. Coast Guard Oceanographic Unit at the Washington, D.C. Navy Yard.

### **RESULTS AND DISCUSSION**

#### **Study Areas**

The locations of the three study areas now being investigated in the Chesapeake Bay nonpoint sources of pollution program are shown in figure 2. The main study site on the Rhode River is marked by an arrow and a ring. The eastern-shore Horn Point site on the Choptank River is circled, and the general area of the Patuxent River in which temporary studies are underway is also circled. Figure 2 shows the various basins under study at the Rhode River study area. Data have been gathered on basins 101, 102, 103, 107, and 108 since early 1974. Basins 105, 106, and 121 were instrumented in 1975. Basins 109, 110, and 122 were instrumented in 1976. Basins 111, 123, and 124 are being instrumented this year. This map also shows the location of rain gages and the weather station. Figure 3 shows an example of a basin land-use map. The main point I wish to convey is the pattern of land use. It is a mosaic with

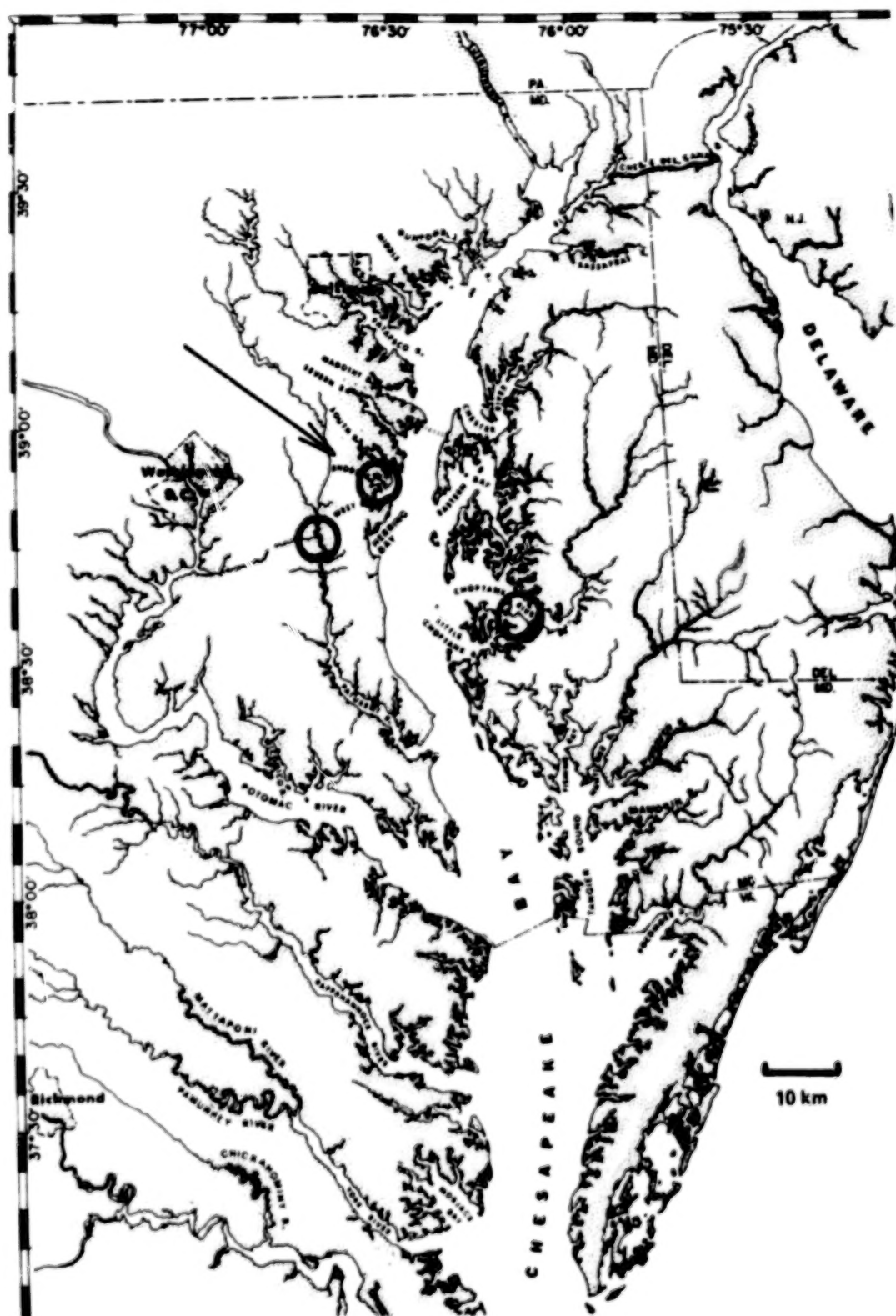


Figure 2. Chesapeake Bay region.

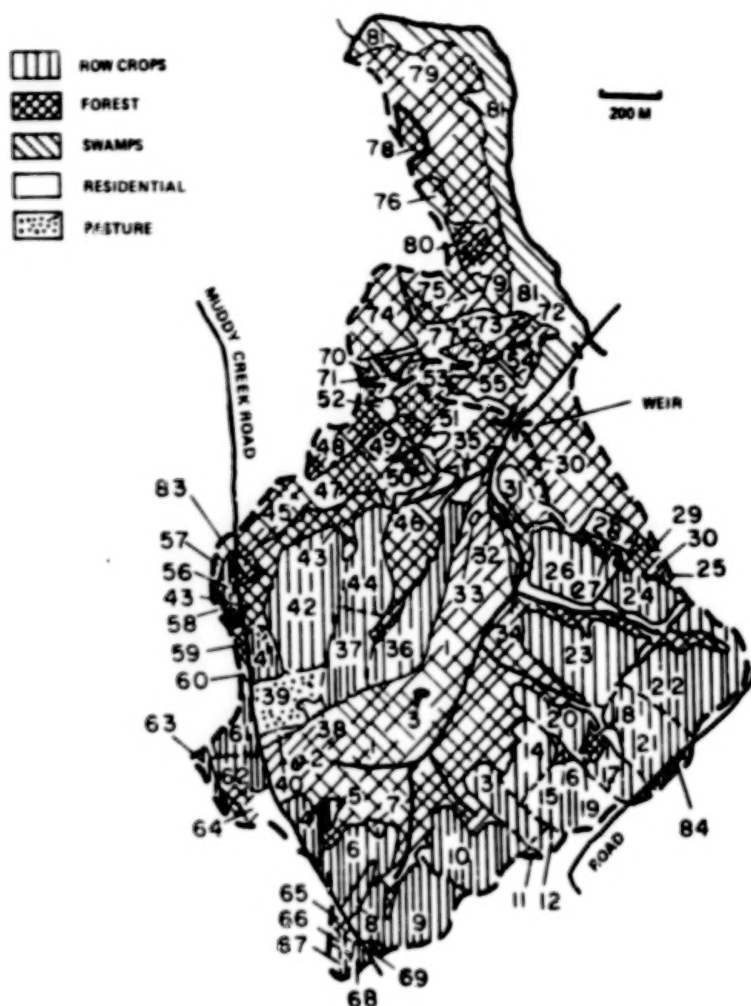


Figure 3. Basin 108 (150 ha) land-use map.

irregularly shaped and variously sized parcels of land blended together in a complex pattern. Some generalizations about land use are possible. Stream banks and wet lowlands or flood plains are forested, whereas uplands of moderate-to-low slope are usually cropland and residential. Also, the average parcel is less than 2 ha. The topography at the Rhode River and Patuxent River sites is similar with slopes averaging about 5 percent, whereas that of the Choptank River site is extremely flat, averaging about 0.1 percent. Overall, average land use of the Rhode River basin is 15.8 percent row crops, 2.2 percent swamps, 1.9 percent tidal marshes, 58.6 percent forest, 10.2 percent pasture, and 11.2 percent residential plus roads.

#### Relationship of Nonpoint Pollution to Land Use

A series of seven Rhode River watersheds that have been monitored for 2 to 3 years have discharged sediment, nutrient, and heavy metal area-yield loadings (wt/ha/year) that varied

from basin to basin by a factor of 3 or 4 on a yearly basis or by up to an order of magnitude on a seasonal basis. The pattern of area-yield loadings between basins has been the same over the period of study, indicating a significant relationship to basin characteristics. The basins are similar with respect to slopes, soils, and weather, and no relationship between basin size and magnitude of discharge was found. However, it appears that differences in land use can be related to area-yield loadings (Correll, Pierce, and Faust, 1975; Correll (in press); Correll et al. (in press); Miklas et al. (in press); Pierce and Dulong (in press); and Wu et al., 1977). It appears that certain basins discharge much higher loads of pollutants than others because of qualitative differences in their storm runoff behavior. Therefore, some with a high proportion of disturbed area discharge storm waters with pollutant concentrations that increase exponentially with storm size; whereas other basins, with land uses that disturb the ecology of the area to a lesser degree, discharge storm waters with relatively low and uniform concentrations of pollutants. Land uses such as feed lots, which load the watershed with high concentrations of materials that are not readily recycled by the system, cause very high runoff concentrations. Even a few feed lots on Rhode River watersheds overwhelmed other land-use effects on those basins. Freshwater swamps affect land runoff by trapping sediments, heavy metals, pesticides, and some nutrients from runoff as it passes through the system. In general, these results tend to point out the close relationship between loading of watersheds and runoff-area yields at least for conservative parameters. Land-use practices that reduce erosion, remove loading as harvested crops, or favor the recycling of materials applied to watersheds reduce runoff-area yields.

Several methods of relating the area-yield loadings of a series of basins to land use with statistical or linear matrix models have been developed (Correll, Pierce, and Faust (1975); and Chirlin and Correll (in press)). These methods calculate average seasonal or yearly area-yield loadings for each land-use category (e.g., 10 kg N/ha year for row crops). These analyses permit comparison of land-use effects on large basins with complex land-use mosaics.

### **Problems Encountered in Land-Use Mapping**

Land use is often analyzed from multispectral images taken from satellites or from photos taken from U-2 airplanes at an elevation of 21,000 meters. In this study, photos taken from an elevation of 1800 meters were used, permitting more resolution of detail. False-color infrared photos were taken in March, and true-color photos were taken in May. A summary of the data obtained for seven Rhode River basins is given in table 1. This table gives the final result of the land-use analysis, including both the analysis of the aerial photos and direct ground-truth survey work. Some categories of land use, such as forest, residential, and roads, are rather easily identified and quantified by this method. Others, such as swamps, row crops, and pastures, are more difficult, even when the winter infrared photos are available for detecting swamps and spring true color for detecting row crops. Table 2 shows the percent error for row crops, swamps, and pasture categories on these seven basins. Error is defined here as percent of area that was assigned a given category on the basis of photo

Table 1  
Land Use on Seven Rhode River Watershed Basins (1976)

Basin	Row Crops (%)	Swamps (%)	Forest (%)	Pasture (%)	Residential & Others (%)	Basin Area (ha)
101	9.9	1.1	56.1	26.9	6.0	226
102	21.6	0.5	54.0	18.1	5.6	192
103	6.1	0.3	76.9	12.4	4.6	253
105	13.7	0.0	80.3	0.3	0.1	37.5
106	28.1	0.0	49.9	20.7	1.3	95.3
107	3.5	0.7	76.2	9.0	5.5	28.2
108	33.0	0.9	52.4	10.8	3.2	150

Table 2  
Percent Error in Land-Use Analysis of Aerial Photos of  
Rhode River Watershed Basins (1976)

Basin	Row Crops	Swamps	Pasture
101	+183	-21	-28
102	+ 33	-30	-16
103	+ 7	-34	+22
105	+ 43	0	+ 9
106	+ 37	0	-65
107	0	-11	-16
108	+ 25	-18	-39
Arithmetic Mean 101-108	+ 47	-16	-19

interpretation but was later found to fall into another category on the basis of ground truth. There was a strong tendency to overestimate row crops. The average was 47 percent, and six basins were overestimated. Pasture was underestimated in five basins, and the average was an underestimate of 19 percent. Swamps were underestimated in all five basins that contained swamps, and the average underestimation was 16 percent. Therefore, although the photos were very useful in determining the boundaries of land-use plots and were reliable for the identification of several categories of land use, they were quite inaccurate for identifying three land-use categories.

### Future Needs for Land-Use Mapping

For land-use mapping of larger areas, it will be necessary to use remote sensing methods. These methods must be refined and tested rigorously against extensive ground truth. The land-use categories must also be selected for sound ecological reasons, such as impact on hydrology or differences in loading or recycling inherent in the category. Therefore, business districts and single-dwelling residential neighborhoods must be separated. Sewered and nonsewered residential areas must also be separated. In rural areas, pasture must be separated from hayfields. Forested swamps must be separated from upland forest.

The need to better define partial contributing areas on watersheds is another type of land-use mapping requirement. These are areas that drain more efficiently into drainage systems and thereby contribute disproportionately to land runoff. These areas may be mapped by infrared photography or multispectral scanning during storm events. Such areas may require special consideration in land-use planning.

### ACKNOWLEDGMENTS

The research program was supported in part by the Environmental Sciences Program, Smithsonian Institution—a series of grants from the Research Applied to National Needs Program, National Science Foundation, administered through the Chesapeake Research Consortium—and by Research Grant No. R804536-01 from the Environmental Protection Agency.

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## PANEL DISCUSSION

### PANEL

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### PROCEEDINGS

#### *HICKMAN:*

I'll direct the initial question to Pete Wagner. In general, when you think about remote sensing, you are willing to give up something for the speed in taking the data for synoptic coverage. My question is: can you afford to give up the sensitivity that you're now getting in the Bay (for instance, on salinity, temperature, or pH) for some type of remote sensing.

*WAGNER:*

I think there are other people who can answer that better than I can because they sample salinity and temperature in the Bay. But I would say, with that caveat, the measurements you make aren't all that sensitive.

*MIHURSKY:*

It depends on your objective. If you're looking at a target species (for example, some important commercial shellfish species), there are two kinds of information that are useful in terms of determining whether an environmental change is going to kill or not. One is the amplitude of the change, and the other is the duration of the change, so that there may only be a single major event in the entire annual period that may be the key limiting event for survival of the species. Therefore, you wouldn't want to miss that.

But, if it's a more stable system without those odd spikes or troughs, there may be some time history in which an averaging might be of some utility. If you're not pushing a limit that might cause a fatality but rather something that would influence growth, you could use an average.

*WAGNER:*

The ground-truth methods aren't all that sensitive now. I don't think you're going to do better than one part per thousand on, for instance, a standard salinity measurement.

*MIHURSKY:*

Well, okay. For a lot of these things, though, you could get more resolution in terms of physical measurements than what the biologist can tell you what it means. You're going to measure temperature to three decimal places, and I can't tell you what it means to a whole number.

*HICKMAN:*

Do we have a question here? John, do you see where some of your acoustic sensors—either in the atmosphere or the underwater acoustic sensors—can fit into the measurement program on the Bay?

*PIJANOWSKI:*

First, I'd like to say that one of the things I like about the large hydraulic model that is being built by the Corps of Engineers is the fact that it's really the first massive model of the entire Bay system. By treating the physical parameters, this model can simulate large influxes like

a large dump of a toxic material and determine time constants over which these things propagate through the Bay. To answer your question, I think that acoustic technology might be applied in the Bay to help maintain the calibration of such a model in order to ensure that natural changes occurring in the Bay are being kept up to date in the physical model. I doubt that the conditions that were in the Bay when the calibration data were taken can be expected to be valid for too long a period of time, especially with the amount of both natural activity in the Bay and man's increasing utilization of it. Acoustic technology offers alternative means of obtaining the type of calibration data that the Corps of Engineers spent millions of dollars collecting, perhaps a little more cheaply.

The atmospheric acoustics would primarily help the investigator who is studying the energy interaction mechanisms between the water at the surface of the Bay and the atmosphere.

*HICKMAN:*

Is the National Oceanic and Atmospheric Administration (NOAA) doing anything in this area?

*PIJANOWSKI:*

Some scientists at the Environmental Research Laboratories are studying the interaction mechanisms, but nothing else that I know of.

*MIHURSKY:*

While you're on the acoustical end of it, I'm not sure whether it was covered so far in the conference or whether it will be covered, but in finfish we're getting into the use of acoustics for giving us biomass estimates of fish. It may be considered a bit of an R&D stage, but it's being applied; and biomass estimates are being made using a side scanning sonar approach. I believe that a reasonably successful use of it has been made in the Potomac estuary in a program in which we're looking at a target species; namely, the striped bass. There are certain advantages in using acoustics with this species in the Potomac that aren't available in other systems with other species; but the point is, I believe it has a lot of potential.

*PIJANOWSKI:*

Studies have been made of target strengths of bladder animals which I feel will be very valuable in the overall application of acoustics in the water.

*MIHURSKY:*

You might be able to sort out which species it is on the basis of the kind of target, strength, quality, and so forth, that's coming back.

*PIJANOWSKI:*

Exactly.

*HICKMAN:*

Warren, could you give the audience a little talk on your ocean-color scanner, what you have accomplished with it, and what you think it might do for the Bay?

*HOVIS:*

I have a comment before I start on that. Are you aware of the acoustic sounding that is being done in the New York Bight studies of sediment flow and dispersion of dumped material by John Proni and a group from Miami? This could be quite valuable potentially in the Bay. If anyone is interested in contacting these gentlemen, I'd be willing to give them the proper address.

Could I ask a question of Mr. Fuller before I go on? You mentioned the Wallops data base. Could we have some idea of what kind of imagery is available, where it is located, and what it costs to get it? Is there a catalog of this data?

*FULLER:*

At the present time, there is a catalog of this data at Wallops. I don't know the full range of imagery available because Wallops has access to the other data bases at some of the other flight centers.

But largely, I think people used imagery taken with multispectral scanners. Near IR was the most useful.

*HOVIS:*

How much would it cost somebody to get it if they needed one? Is it free?

*FULLER:*

In most cases, it was given free. Most of the original 24 went down and actually looked at the imagery and discussed the imagery at the Wallops Flight Center.

*HOVIS:*

I was asked to discuss an instrument that will fly on a Nimbus-G due for launch about October 1978. The coastal-zone color scanner is the first instrument that we know of—at least in unclassified regions—that is devoted to measuring water color. Others have done it,

but they were designed for other purposes. It has six spectral bands, four narrow bands 20 nanometers wide and centered at 443, 520, 550, and 679 nanometers; one wider band, 700 to 800 nanometers, which you may recognize as a Landsat band; and a registered 10.5- to 12.5-micron thermal band.

The important thing about it is that the dynamic range of the instrument is entirely devoted to water in the first four bands and that the digitization level is 8 bits, giving 256 quantization levels instead of 64 as in Landsat. Unfortunately, because of the telemetry limits from Nimbus, the resolution is about 800 kilometers at nadir. However, the swath width is 1600 kilometers, so that areas such as the Bay that would require repeated coverage would be seen for about 4 days in a row, missed for 1 day, picked up for another 4 days, and missed for a day. The East Coast of the United States and the West Coast are prime areas. The sensor will be operated whenever conditions are appropriate; that is, when weather conditions are clear as it passes over the Chesapeake Bay.

The data will be archived and distributed by the Environmental Data Service of NOAA located at the World Weather Building on the Beltway around Washington. The data will be for sale at approximately \$5 a copy for a transparency with all of the spectral bands shown on it. There will be some minimal processing beyond calibration—namely, offset—to increase the contrast of the signal because of the very large contribution from the atmosphere rather than from the ocean.

Because about 80 percent of the signal is backscatter, we'll offset that to give a reasonably high contrast, but still a calibrated picture. All of the data will also be available in calibrated tapes for about \$60 a copy. One tape would contain three images, or about 2 minutes. Therefore, one tape would represent about 6 minutes of recorded data from the spacecraft. The launch date is about October 1978. I'd also like to mention the fact that there are other satellites in operation now and planned for later on.

A question was put on the board earlier: What happens when Landsat isn't around? Is there any other satellite available? None have the resolution of Landsat, at least not in the unclassified regime. There is a satellite series now in operation; you've probably heard of the NOAA series that has a daylight band of about 1-kilometer resolution and a thermal band of approximately the same resolution. Two satellites are in orbit at all times, giving global coverage.

Coming along for TIROS-N is a device called the Advanced Very High Resolution Radiometer (AVHRR) that will have 1-kilometer resolution and, in about the third or fourth model, will have a correction for atmospheric water vapor and temperature measurement that we hope will give absolute sea-surface temperatures to one-half a degree as opposed to the equivalent blackbody temperatures we're getting now that can be in error by as much as 6 to 10 degrees because of unknown water vapor in the path. The Geostationary Operational Environmental

Satellite (GOES) satellite that was mentioned earlier in the data-collection platform paper also provides imagery every one-half hour in daylight and darkness. It has a daylight band of about 1-kilometer resolution and a thermal band of 8-kilometer resolution. It cranks out an image every one-half hour, 24 hours a day, 365 days a year. The GOES data are now retained for only 2 weeks, but will soon be retained for 90 days. If you want tapes of GOES data, you must request the tapes before the archival period is over—2 weeks now, 90 days in a few months.

Another satellite, whose name—Seasat—tells you what it's devoted to is coming along that is devoted more to physical oceanography. One of the devices on board is called a synthetic aperture radar. It's an active radar device using synthetic aperture techniques with an extremely high bandwidth—about 102 million bits per second—recorded in real time only. No tape recorder on Seasat could handle that kind of bandwidth. Of course, one of the prime sites will be the Chesapeake Bay and the Atlantic coast. The nominal spatial resolution for a synthetic aperture of this type is about 25 meters, but if you get the wide-open bandwidth, you can get down to about 7.5 meters. Although it was made to look for waves—wind and action of waves, disturbances and devices on the surface are being detected by synthetic aperture radar. By the way, Seasat is also scheduled for March 1978. The schedule says May. I still believe it will be launched about October, but of course, that's an unofficial position.

Also on Seasat are a microwave altimeter for measuring sea topography; a scanning multi-frequency microwave radiometer with five bands for sea-surface temperature, roughness, wind speed; a very coarse device for imaging of visible and infrared radiometer, and a device called a Radscat—a radiometer scatterometer that will measure ocean surface conditions by broadcasting an active radar pulse and that will measure backscatter.

All of these satellites are either in orbit or will be coming along very soon. I'd be glad to furnish more details to whomever asked "What else is there besides Landsat?"

*HICKMAN:*

I just had an interesting discussion on remote sensors with Arch Park; Arch, would you like to say something about microwave scanners?

*PARK:*

There is a plan to launch a radar to look at the land on the second orbital flight test of Shuttle. It will be a Seasat radar (that is, it will be an L-band radar with the same spatial resolution as Seasat (25 meters)), except that its incidence angle and polarization characteristics will be optimized for the land instead of the sea. A modified Goodyear-102 radar will be flown on one of the early space labs.

Those of you who have been looking at radar know that the most popular and widely used radar that exists in the civilian community is an APQ102. It is an X-band system and has very good resolution. It is really a terrain-type of radar. This radar will be optimized to look at both vegetation and the terrain; its incidence angle will go out to about 65 degrees, which is getting close to the coastal plain type of incidence angle for geology. They would prefer to go to about 85 degrees, and it's getting a little bit beyond what the vegetation expert would prefer, which is 45 to 55 degrees. But the trade will be that they will both look at 65 degrees, and the belief is that both vegetation and geology will benefit. Geology is a tough application for radar because, in mountainous terrain, they'd like an incidence angle of about 40 degrees and, on the coastal plains, they'd like 85 degrees, which means you've got to do both; and so, they're never happy with any single design.

Active radar or active microwave is good experiment for the Shuttle, which is a big vehicle that can handle lots of power and lots of weight; you don't have to microminiaturize anything. It is a very good workhorse for active microwave systems. The thing that's got all of us excited is that most of us in terrain-type work have a couple of requirements for microwave. One of them is vegetation identification using frequent observations. We've had some very encouraging work in that regard. We have used a Ku-band system that is affected somewhat by the atmosphere. It will be farther out in the development schedule than even the 102. The second requirement is that we would like to make soil-moisture measurements directly, instead of using models that are currently evapo-transpiration models using local weather stations on the surface. This appears to have great promise. It is likely to be a C-band application rather than what you probably have heard is an L-band application. It looks as though we might get a radar that combines both C-band and Ku-band in which we can do soil-moisture measurements directly with a very steep depression angle. The look angle from nadir is about 7 degrees looking almost straight down. The Ku-band system will characterize the surface in terms of vegetation and, between the two, we can process the data to extract soil moisture directly. So, it's an exciting future for remote sensing that we are not discussing at the present, but it's out there, and I think it's pretty important.

*HICKMAN:*

Bill, have you heard anything tonight that impresses you?

*COOK:*

I think the studies that Dr. Mihursky is doing with the energy flows following along the lines of Odum has impressed me more than anything else that I've heard. I understand a bit about remote sensing, but I have yet to have anybody come up with an idea that really impresses me.



People talk about the fact that the Environmental Protection Agency (EPA) has \$5 million for the Chesapeake Bay Program; maybe we're not quite as lucky as some people are alluding us to be. But I don't see anything yet that impressed me enough to say, "We can do this with remote sensing." Somebody might come up with a proposal, a portion of which might be done with remote sensing, but the way I see it, that still is yet to be presented. But, unfortunately, I'm not impressed with what I've seen so far in relation to the Bay. I hope I didn't offend anybody by saying that.

*HICKMAN:*

Is everybody just going to sit still? It deserves an answer.

*PIJANOWSKI:*

I think the concept of looking at the entire Chesapeake Bay as a system is a fairly massive concept, and it takes someone who is—I wouldn't want to say a massive thinker—but someone who likes to bite off a pretty big chunk to treat the entire Bay area as a system. I think it's the thing you have to do in order to obtain results that are useful for accurate predictions and for establishing credible standards for regulations.

Back to my first comment, I think the step that the Corps of Engineers has taken in its hydraulic model of the Bay, from which you can make predictions, is a significant step. Secondly, the analytical model suggested by Dr. Mihursky—that of looking at the entire Bay from the point of energy balance, including the contribution of man to energy exchange—represents another big step toward solution of the overall Bay problem.

*KEMP:*

Let me reiterate in response to that point. Our point of view on how to deal with this vast complexity of such an enormous system as the Chesapeake Bay (involving all the human interactions and all the natural interactions) utilizes this notion of identifying hierarchies of scale. This is a way to view some of that complexity piecemeal—like a piecewise linearization of your thinking process; and then you only have to focus on the connections between the various scales in order to integrate the whole system into a workable model. This technique has been used a lot in our computer simulation models.

*PARK:*

My background is in biology, and I find it very difficult to believe that, biologically, the Chesapeake Bay is a system. I don't think you have wrestled with the problem of how one intelligently samples the Bay, given the fact that \$5 million is a very small amount of money if you're going to enumerate the Bay. If you're going to sample the Bay, the first rule of statistics is that you have to define the population, and I find it a very uncomfortable



situation as a biologist to believe that the population of interest is the entire Chesapeake Bay. I think there are subsets of the Bay that represent true biological populations in the statistical sense, but I have no comfortable feeling that we know where those boundaries are at this point.

*MIHURSKY:*

One way you can treat that is, for example, the work we were doing on the Potomac with regard to a target species. This question of what is the population—the applied question—is to put a power plant or a number of power plants on that system and have a power plant design that might crop some segment of that population. How much dare you crop that population? Well, first you've got to find out what the size of the population is.

Although the striped bass distribute themselves up and down the entire East Coast, when it comes time for spawning, a definable subpopulation moves up into that Potomac subsystem and is genetically and geographically isolated. You can study it and then put a framework around that and start to quantify how many spawners move up there. In 1974, using acoustical techniques, we estimated 1 million spawners, and, using some water-truth technique of conventional netting, we got an average size of 20 pounds. Therefore, we had 20 million pounds of stripers moving up into that system. You come up with a fecundity estimate from your water-truth work, and then you go through your netting technique—how many eggs, how many larvae? You pick up natural mortality rates and then superimpose plant mortality rates on various life history stages and say, "Does that plant fit under these circumstances with regard to that population?" The objective is that you want to be able to permit some continued yield from that population. In that sense, I think you could put some boundary conditions around part of the Chesapeake Bay system and call it a system.

*WAGNER:*

Isn't the system defined by the fact that things interact within it? If you wiggle it here, it affects things down here. How about any species that uses the whole Bay, such as crabs. You couldn't cut it up without interfering with their life history in a very basic way. I would think it would be the same thing with the circulation patterns. If you turn off the Susquehanna, you're going to feel it at Norfolk. I don't see how you could divide it.

*PARK:*

The atmosphere relates to the biosphere, you know. You can treat it that way, but, if you're really going to talk about cause-and-effect relationships, you've got to subdivide that biological work. It's not the same thing.

*MIHURSKY:*

I think the problem you're having is that it is not a closed system; it has boundaries, and things come in and out of these boundaries. If you can identify what those boundaries are, you can treat it as a blackbox circumstance and then work within the area that you're targeting to try to answer a question.

*HILL:*

I've seen the Bay system divided several times today in several studies. The Bay was divided into basins like the Patuxent and the Potomac. I've participated in one in particular in 1973—Dr. Lear will probably remember—where we had 8 to 10 boats on the Patuxent with overflights. That was a massive program.

Is that what you're talking about—not dividing up the population of crabs within the Bay, but approaching it as a total system? We've been talking about studying the entire Bay all at once, and that's what you can see in a Landsat picture. But, that's a hard way to go after it. I would like to see a basin-by-basin study.

*PRICE:*

I want to make some comments about how I think the present Landsat systems can be used from what I've seen and Pete Wagner's and Ted Robinson's talk, and maybe make some predictions about how I see that Landsat-C can be used. Arch Park has commented on the Shuttle and alluded to Landsat-D. The two areas in which you can use Landsat-1 and -2 are in eutrophication studies of the Bay. I think you need the synoptic repetitive coverage of the Bay to really get a good handle on that. Such studies have been done on the Delaware Bay, and they're being done on a lot of the lakes in Michigan at the present. They're having good success in studying eutrophication of those particular water bodies.

Secondly, I think that you can study the sedimentation and turbidity patterns in the Bay and infer the circulation patterns from them. I think that, if the sedimentation is heavy enough, you can infer circulation patterns—if that's one of the parameters you need to measure.

*HICKMAN:*

What scanner are you mainly talking about?

*PRICE:*

I'm talking about the multispectral scanner (MSS) presently flown on Landsat-1 and -2, because those are essentially the only sensors we're using right now. Now, those are just Chesapeake Bay studies, but I think the title of this is the "Chesapeake Bay Regional

Symposium." So, I'll get back to a little land use. For the Landsat-C time frame, we haven't emphasized the return-beam vidicon (RBV) sensor much up to this point because it failed very early after the launch of Landsat-1. By Landsat-2, we decided that the MSS should be the prime sensor because the results from Landsat-1 were very successful. But, in the Landsat-C time frame, we will have improved the resolution to about 37 or 40 meters, and I think we might be reaching a point at which Landsat data will be useful to the planner—at least to the county planner, the regional planner, and possibly to the local planner. I'm not that familiar with city planning. Maybe you really do need to count buildings and rooftops. I think there is some application there.

Another improvement on Landsat-C is the addition of a thermal channel to the MSS itself. This, of course, provides the opportunity to monitor heat pollution from power plants or whatever you might want to do in that area.

*ROBINSON:*

I would like to say a bit about the challenge of the concept of performing a systems analysis of the entire Bay. Although I didn't address it in my talk, my primary job is conducting a study of the Chesapeake Bay for the Corps of Engineers, and the primary tool in this study is going to be the hydraulic model. We've been giving a lot of thought to whether or not you can treat the Bay as an entire entity, and I think the answer is both yes and no. It's like any systems analysis. You have to break it down into its subelements first and then put the subelements back together. We view these subelements in two perspectives; one of these is resource-use categories. There are about 15 use categories—recreation, water supply, water quality, fishing, land use, etc.—and they represent one of the subsets that we're looking at.

The EPA study is addressing one of those subsets—the water-quality aspects of the Bay—and we've been working very closely together through the years on this. The other portion of these subsets includes the various areas of the Bay and their unique characteristics in terms of biology and land use or what have you.

We approach system analysis by looking at small portions of the Bay's resources, but, sometimes in the process, you must bring it all together, because there is no doubt that the Chesapeake Bay is one entity, and what happens up in the Susquehanna River has a definite influence on what's happening down at Norfolk or in the James River.

Also, in terms of our biological knowledge, I was very naive, not being a biologist. When we started the project, I went to the biologist and said, "I want a cause-and-effect relationship. If we put one BTU of heat in, what happens?" Of course, they could not answer such a question. We ended up modestly funding the Chesapeake Research Consortium to give us the state-of-the-art knowledge of the biota of the Chesapeake Bay. They've already done some of this work. It's been published in our Existing Conditions Report. In about a month,

we're coming out with a Future Conditions Report, which will extend this work somewhat. It's by no means complete, but it's a darn good start in giving us a statement of our present knowledge of the biota of the Chesapeake Bay.

*WILKERSON:*

I have a couple of questions.

Bob, you mentioned inferring currents from the turbidity data on Landsat-1 and -2. Have those experiments been done—that is, using the Landsat imagery and then the ground-truth measurements to show that the results you get from the Landsat analysis are indeed consistent with the currents observed on the surface?

*PRICE:*

I think this is exactly the sort of correlation that's being performed in the Delaware Bay by Vic Klemas at the University of Delaware. He's relating considerable sea truth and ground truth to the turbidity patterns that he can pick out from the Landsat data.

I also think that you can get—I don't want to call them circulation patterns—but tidal patterns from waste dump (for example, the New York Bight). You can very clearly see where the pattern of flow is by monitoring the acid dump, and you can follow that very clearly on Landsat data.

*HILL:*

Getting back to Mr. Price, you stressed that eutrophication could be studied with Landsat. What is your definition of eutrophication, and are you looking at BOD, chlorophyll, and suspended sediments. Just what are you getting at there?

*PRICE:*

There are about nine standard parameters for eutrophication. You've just named about three, and someone else named about six of the others during his talk. I'm not a biologist, so I can't remember them all off the top of my head. A fellow named Griggs, who's working in Michigan, has had a good deal of success in correlating certain spectral signatures that are related to color in the visible bands, etc., to some of these eutrophication parameters. He's been able to monitor the water quality in lakes in Michigan. In fact, they're working with the EPA in Michigan in the Resources Department of the State of Michigan in telling them, "These lakes are going bad, and you'd better have some people do something about it." So, yes, you don't sense those parameters directly, but they're having good success at correlating the spectral signatures to certain parameters that indicate eutrophication.

*HICKMAN:*

We'll take about another couple of questions, and then we'll close.

*WAGNER:*

This might agree with some of your concerns. If you're an experimental scientist who has not worked in the Bay, you come in and look at what experimental scientists who work in the Bay do. You're struck by how primitive the state of the art of actual measurements is in the way things are done: nets literally going overboard, thermometers going overboard, white disks going overboard to see how turbid the water is, and so forth. You just get the feeling that measurement technology is way ahead of that in principle and that there's a big hiatus between what you ought to be able to do without any new physics or anything being discovered and what's actually done every afternoon on the boat. That's what I was hoping would come out of this conference.

*COOK:*

Yes, that's exactly what I'm driving at. I realize those techniques exist, but I'd like to see somebody come up with an idea, sit down or present it, and say, "Look, this is where we can go beyond that with this type of technology."

*WAGNER:*

We were talking about two of those today. One would be a lidar measurement of turbidity, not just on the surface but maybe a couple of meters down. Dan, you were involved in that conversation. That would be a big plus. That would be of major assistance. And another one came up this afternoon—measurements of salinity and temperature, even just at the surface from overhead.

*WILKERSON:*

It is my impression that we've heard a lot about fairly successful remote sensing methods, and I'm puzzled as to what your goals are, that you seem so unsatisfied by the things that have been discussed. Could we hear something about these goals?

*COOK:*

Well, I think we're in the process of still trying to develop those goals. I would like to see some sort of a team concept in which your technology and our program could work together—or the technology that's here could work together towards developing those goals—rather than having to display those goals to you and then you develop around that. I see the team concept as being much more valuable. The people here are the technologists that know what remote

sensing can do, and a number of them have studied the Bay in depth. I would like to see them, along with a few other sources—not just including the scientific world—say, “Look, this is what we have to do, and this is how we can get there.” If we can communicate that way—that’s the biggest word, communication—then maybe we can effect something that’s valuable.

*MIHURSKY:*

I’m a trained biologist, trained as an ecologist, trained to try to dare look at an entire system. One of you asked how we dare take on some of these systems as if you have to be a crazy man to try to interpret and integrate everything. I guess maybe you do have to be a bit of a crazy man. However, in terms of remote sensing, when it first came about—I think Dick Anderson was here—Patuxent was going to use some aerial photography and what have you to try to map vegetation and thermal plumes using IR. We sort of cut our teeth a little bit on the Patuxent. And I was wondering how is this going to work? You sort of have to get wet in the water to find out what’s down there. That’s the way you’re trained. But, when I sat back and thought about the way remote sensing might be able to serve us, I thought it was a matter of perception.

And, just like with Mike and myself trying to get a point across to you in terms of looking at these systems, it’s sort of an abstract way in terms of energy. What we’re trying to say is really hard to understand, perhaps. You can’t see it. If you’re a biologist and you thrash around in that water, you get to know the various species and all the life history patterns and how they move around. In your mind’s eye, you can see the dynamics of this system, and you see the boundaries of the population. You can feel it. You can sort of see it. But, if you haven’t had all that background and training, I think you really can’t see it. When we try to interact with people who are not trained like we are, we sometimes see that the wall drops, and they don’t know what we’re talking about.

Also, with the Chesapeake Bay, how dare you try to take on that whole system? Looking back into the history of the Bay, you had the Chesapeake Biological Laboratory, the Chesapeake Bay Institute, and all these little groups of biologists grousing around in their own little areas. You saw very few programs that dared try to take on the entire Bay. Everybody appreciated that it was very complex, like the diagram that Mike put on the board. Well, that’s the way the systems are. That’s really a simplified diagram of how some of these systems are connected, and it kind of blows your mind. But the actual system is even far more complicated than that. As an ecologist, though, you try to understand that, **put all** that together, and try to help out in decision-making.

But, to get back to the Bay, I see remote sensing as a tool that would enable us to perceive this system in a wiser way. When we talk about energy flow in the system, for example, in the summertime, these biological systems are soaking up the Sun’s energy. It’s really churning along. In the wintertime, it’s sort of humming along at a low level. Well, how do you



see that? You can have almost a moving picture approach with a satellite shot of the Bay, and you can see the pulsing of this system in terms of color and feature changes. I think this has utility in terms of how a legislator, a user, or a regional planner perceives the Bay in terms of trying to grab hold of a little bit of the dynamic nature of the Bay. You look at a map, and that's pretty static. You get out there on a boat, and you're sort of too close to the trees to see the forest. But the Chesapeake Bay hydraulic model shows the Bay in miniature. You're pumping water in here, it's flowing here, you see things moving, and you say, "Lo and behold, here are some people grabbing hold of that entire Bay." That model sort of symbolized the entire Bay.

I think a barrier has been overcome in terms of our perception of the Bay and the feeling that maybe we can dare to take on that whole system. Maybe I'm being too vague, but I think there is that kind of a conceptual barrier that we've got to overcome individually and collectively. We must get beyond the individual little laboratory like the Chesapeake Biological Laboratory. You don't have the critical mass of hedge, and one person can't be an Aristotle to try to take on an entire system such as the Bay, which is very complex and involved.

I think there are two things that remote sensing can service in the larger macroscopic sense, and there are these other details that we touched on, like work on acoustics with the striped bass. I think there's some interesting use of these tools that have been applied, and I feel a little positive about the whole thing.

#### *HICKMAN:*

I think we will end here. I have just a couple of comments. I think we should do a little more thinking about some of the things we've brought up tonight and the 17 questions that appeared in your packet, which are suggested topics for Session V that came out of your questionnaires. They represent your thoughts.

The speakers and some of the panelists tonight have turned in final papers. Therefore, if you want a specific paper before the proceedings appear, contact the individual author.

Finally, Dr. Pemberton obtained a minicourse from the University of Purdue on the educational aspect of remote sensing. This is composed of a series of about 20 lectures. A set of these courses are out in the Devonian Room for you to take a look at. It looks like a very exciting educational tool. Please don't take them.

Tomorrow, if I have an opportunity, I'll try to set up a display showing the slides and talk (on cassette) that go along with the printed material.

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**SESSION 4**

**POLLUTION PROBLEMS OF THE  
CHESAPEAKE BAY REGION**

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## INTRODUCTION

**Thomas D. Wilkerson**

*Institute for Physical Science and Technology  
University of Maryland  
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and

**Donald W. Lear, Jr.**

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This session deals with the pollution problems of the Chesapeake Bay region and how they are, or may be, approached by various techniques of remote sensing. The problems discussed here are dredging and power-plant operations and the effects of excessive nutrients and turbidity on flora and fauna. The techniques include Landsat and aerial photography of land use and of sediment and chlorophyll in the water, long-path absorption by pollutant molecules, laser probing for various parameters of the water environment and for aerosol/molecular content of the atmosphere, and "underwater satellites" that can sense sedimentary pollution by nuclear-excitation methods.

The papers presented here represent various stages of completion of remote sensing technology. A consensus that emerged from this session and from the discussions that followed it was that research and development needs to be increased considerably for two reasons: (1) with developing concepts, such as the laser and nuclear probes (which tend to be relatively costly for a single device), the measurement potential is so great that accelerated development is required; and (2) concepts based on more familiar technology, such as aerial photography, are still being refined, and, for the realization of their full potential, concurrent extensive "ground-truth" measurement programs are necessary.

The scope of the problems addressed here and the range of techniques applicable both now and in the near future are broad. One suspects that all of these and more will need to be considered in truly assessing man's impact on the Chesapeake Bay system.

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## AN OVERVIEW OF DREDGING OPERATIONS IN THE CHESAPEAKE BAY

**Ronald H. Silver**

*U.S. Army Corps of Engineers  
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The Chesapeake Bay is the largest estuary in the United States and is perhaps one of the most useful in the world. Being a drowned valley of the Susquehanna River, it has hundreds of peripheral creeks, rivers, and bays, a very long shoreline, and extensive shallow water areas. It is approximately 310 km (190 mi) long, 8 to 48 km (5 to 30 mi) wide, and up to 53 m (175 ft) deep. The average depth of the open Bay is 8.4 m (27.6 ft), whereas the average depth of the entire estuary is 6.5 m (21.2 ft). The open Bay has a surface area of approximately 6500 km<sup>2</sup> (2500 mi<sup>2</sup>), and including tributaries, the total estuarine system has an area of approximately 11,500 km<sup>2</sup> (4400 mi<sup>2</sup>). The total shoreline of the Bay and its tributaries is estimated to be 13,000 km (8100 mi), with 6400 km (4000 mi) in Maryland and 6600 km (4100 mi) in Virginia. If all of the water were drained from the Chesapeake Bay, the ancient channel of the Susquehanna River would be visible and the extensive shallow shoulders would be apparent, as well as the massive quantities of soft sediment that are slowly filling the Bay and its tributaries. This slow filling of the Chesapeake Bay and man's desire to maintain the commercial ports and recreational channels located on the Bay has necessitated dredging. The U.S. Army Corps of Engineers maintains approximately 120 federal navigation projects in the Chesapeake Bay and its tributaries. There are 95 authorized navigation projects (20 of which are inactive) under the supervision of the Baltimore District. The Norfolk District has 52 authorized projects, 12 of which are inactive. These projects annually report either seafood-related commerce or recreational activities, but the required maintenance of these projects result in varied environmental impacts to the total ecosystem of the Bay. In addition, Baltimore and Newport News/Norfolk Harbors, two of the five major seaports on the North Atlantic Coast, are located on the Chesapeake Bay. Further, the Chesapeake and Delaware Canal that provides the port of Baltimore with a second access route to the shipping lanes of the world is located at the head of the Bay. Maintenance of these major navigation projects is accomplished by different dredging operations, such as seagoing hopper, hydraulic pipeline, clamshell, dipper, and ladder dredges, depending on the amount and type of material to be removed, water depth, and location of disposal sites. These maintenance activities have been a responsibility of the Corps of Engineers. Concurrent with this dredging, however, others have based their incomes and quality of life on the rich, biological bounties found in the Chesapeake Bay, including finfish and shellfish. Herein lies the beginnings of a paradoxical conflict.

The dredging and disposal of shoaled material could potentially threaten oyster beds and fish nursery areas if not carefully evaluated and implemented. The conflicting interests of environmental and economic concerns create a dilemma to which there is currently no readily available answer. Several environmental laws have been passed, however, that supplement the Corps of Engineers' original mandate as spelled out by the River and Harbor Act of 1899. New laws (such as the Federal Water Pollution Control Act, the National Environmental Policy Act, the Fish and Wildlife Coordination Act, the Coastal Zone Management Act, and the Marine Protection, Research, and Sanctuaries Act or Ocean Dumping Act) have affected the manner in which dredging is conducted. Although these laws and attendant regulations indicate some specific actions (such as preparing an Environmental Impact Statement, issuing a Public Notice, holding a Public Hearing, and increasing coordination with various state and federal environmental agencies and the public), the intent is to require the Corps of Engineers and other agencies to consider a broad range of factors that may affect the public interest. In some instances, however, this has resulted in the deferral of, or added expense for maintaining, federal navigation projects.

Two major factors that are primarily responsible for the deferral or added expense of maintaining a project are time restraints on dredging/disposal activities and the use of upland confined disposal sites rather than unconfined overboard ones. Several innovative techniques have evolved in response to these problems. Use of dredged material for marsh creation has been successful at Slaughter Creek and Honga River. Future plans include a marsh restoration project at Dyke Marsh on the Potomac River. Congress has recognized the increased expense of this alternative and has recently enacted the Water Resources Development Act of 1976, which authorizes the expenditure of up to \$400,000 per project if wetland creation or restoration alternatives are employed.

Another unique innovation has been the formation of the Delmarva Water Transport Committee by private citizens on the eastern shore of Maryland. This committee has aided the Corps of Engineers in locating the suitable upland disposal areas required during maintenance of several federal navigation projects on the Delmarva Peninsula.

The proposed deepening of the Baltimore Harbor approach channels to 15.2 m (50 ft) has spurred the development of a multimillion dollar, 4452 km<sup>2</sup> (1100-acre) confined disposal site at Hart-Miller Island. This area will contain sediments that have industrial contaminants and are not suitable for other uses. Craney Island, an operational disposal area near Norfolk, Virginia, is similar to the proposed Hart-Miller Island facility.

Time restraints imposed on dredging/disposal activities have forced the vast majority of dredging to be done during the winter. This has an obvious impact on contract plant and personnel. The unusually severe winter this year dramatically illustrates many of the problems encountered. Unfortunately, until the potential impacts of dredging/disposal activities are better understood, these time restrictions will continue to defer or add to the expense of maintenance dredging. The Corps of Engineers is now attempting to determine the effects

of dredging/disposal operations by conducting a 5-year nationwide study entitled the "Dredged Material Research Program." This program utilizes ongoing dredging/disposal activities conducted by the various Districts of the Corps of Engineers, as well as scientists and experiments within academia.

The oldest continuing civil-works activity of the Corps of Engineers is dredging. Maintenance and new-work dredging is performed nationwide by the Corps of Engineers on 40,000 km (25,000 mi) of inland and intracoastal waterways at an annual cost of \$160 million. The Baltimore District annually dredges 1.1 million m<sup>3</sup> (1.4 million yd<sup>3</sup>) of material from the Chesapeake Bay and its tributaries.

Dredging is the removal of material, usually from under the water, for the purpose of constructing new canals or waterways, maintaining existing channel depths and widths, obtaining fill for replenishing beaches, constructing dikes and levees, and obtaining construction materials, including hard rock that has been broken by blasting.

The hydraulic dredge is now the most highly developed and economical dredging tool in the United States. The cutterhead pipeline dredge, dustpan dredge, and seagoing hopper dredge are hydraulic dredges. The bucket dredge, which uses the clamshell bucket for most work and the orange peel bucket for rock or debris in restricted working space, is usually used on many smaller jobs. The dipper dredge is similar to the bucket dredge, but is equipped with a positive digging mechanism like the familiar power shovel, which enables it to root out and excavate rock or resistant materials in a similar manner.

The three dredges most commonly used in the Chesapeake Bay area are the hopper dredge, the cutterhead hydraulic pipeline dredge, and the clamshell dredge. The hopper dredge is a seagoing vessel that is capable of disposing of material at great distances from the point at which it was dredged. The bottom material is raised by dredge pumps through dragarms that are large suction pipes ranging from 30 to 91 cm (12 to 36 in.) in diameter. The dragarms may be located on the sides, center, or stern of the dredge. The Corps of Engineers owns and operates 16 hopper dredges that range from 548.6 to 1600.2 m (180 to 525 ft) in length and have hopper capacities from 382.3 to 6116.8 m<sup>3</sup> (500 to 8000 yd<sup>3</sup>). Dredging can be performed in depths from 30.48 to 188.97 m (10 to 62 ft).

When working, the hopper dredge moves along its course under its own power at a ground speed of 3.2 to 4.8 kmph (2 to 3 mph) with the drags in contact with the bed material. The material, mixed with water, is lifted hydraulically by the dredge pumps and is discharged into the hoppers. The solid particles of material settle to the bottom of the hoppers, and the excess water passes overboard through overflow troughs. After the hoppers are filled, the dragarms are raised, and the dredge proceeds at full speed to the disposal site where the loaded hoppers are emptied by opening the bottom doors. The doors are then closed, and the dredge returns to the dredging area to repeat the cycle of operation.

Cutterhead hydraulic pipeline dredges are the most widely used. The distinctive mechanical feature is the cutterhead that carves clay, breaks off chunks of the softer rocks such as coral or shale, and stirs up gravel and sand so that the stream of suction water is constantly loaded to capacity with excavated material. The type of material that is being dredged determines how fast the dredge can step forward. Floating pipelines transport the dredged material from the dredge to the disposal area. Most cutterhead dredges are not self-propelled and are towed to the work site. They vary in size from 15.2 to 91.4 cm (6 to 36 in.) in discharge pipeline diameter and are powered by diesel or electricity. The smaller dredges are used primarily in channel maintenance work that does not require much more than a 758-m (2500-ft) pumping distance. The larger dredges can pump material through discharge lines over 3.2 km (2 mi) long. Hydraulic dredges operate best in soft or loose material, are adaptable to many types of work, and are generally efficient in all types of work.

The clamshell dredge is essentially a stiff-leg derrick on a floating platform. The clamshell bucket consists of two quarter cylinders pinned together on the axis with projecting lever arms laced together with wire rope passing over sheaves on the levers. This type of bucket is a direct evolution from the first primitive spoon and bucket dredges. It has been highly developed into an efficient and economical machine for handling earth, soft clay, sand, and mud. The machine is slow moving, and economy of operation arises from the small operating crew of 8 to 15 men per shift and the use of large buckets with a capacity of up to 15.2 m<sup>3</sup> (20 yd<sup>3</sup>).

Maintenance dredging of the approach channels to the Baltimore Harbor project was accomplished by the bucket and scow method in FY 1976 and 1977. This operation involved a 13.7-m<sup>3</sup> (18-yd<sup>3</sup>) bucket dredge and several 1520-m<sup>3</sup> (2000-yd<sup>3</sup>) bottom dumping scows. The dredged material was deposited in open water at an approved disposal site.

Dredging is a frequent and widespread activity of the Corps of Engineers or others under permits issued by the Corps. These dredging activities usually affect the environment. The potential ecological impacts of dredging and disposal can be categorized as resulting from physical or chemical-biological interactive effects.

Physical effects are often straightforward and evaluation may often be made without laboratory tests by examining the character of the dredged material and the nature of the disposal site. One of the most important physical effects considered is degradation or destruction of wetland resources. Another obvious physical effect that can be anticipated at an open-water disposal site is a covering of part of the benthic community with a possible change in community structure or function and physical nature of the system. Filling may also permanently change the hydrography of an area with subsequent changes in circulation patterns and shoaling areas.

Chemical-biological interactive effects, however, are usually difficult to predict. There are many concerns about the potential environmental consequences of various dredging disposal



operations. The principal concerns associated with open-water disposal of material that contains contaminants are the potential effects on the water column and benthic communities caused by the contaminants. Considering the complexity of the involved ecosystems, no single test can be used to evaluate all effects of dredging/disposal operations. However, there are guidelines that provide options to be used in the technical evaluation of the proposed activities. Release of chemical contaminants from the sediment to the water column may be simulated by an elutriate test. Expected effects, such as toxicity, stimulation, inhibition, or bio-accumulation, may be estimated by bioassays. Comparison of, as well as the suitability of, the proposed disposal sites may be evaluated by total sediment analysis or bioevaluation.

Although certain situations may not require testing of the dredged material, other situations may require one or more of the testing procedures. It must be noted, however, that there are limitations associated with using the results obtained from each procedure. These limitations must be considered when selecting, conducting, and evaluating the results of the following procedures.

The elutriate test is a simplified simulation of the dredging and disposal process in which predetermined amounts of dredging site water and sediment are mixed together to approximate a dredged material slurry. The elutriate is the supernatant resulting from the vigorous 30-minute shaking of one part bottom sediment from the dredging site with four parts water (vol/vol) collected from the dredging site, followed by a 1-hour settling time and appropriate centrifugation and 0.45  $\mu$  filtration. Results of the analysis of the elutriate approximate the dissolved constituent concentration for a dredged-material disposal operation at the moment of discharge.

Bioassays are procedures that use living organisms to detect or measure the presence of available toxic inhibitory or stimulatory substances. The procedure for evaluating dredged material requires exposure of the test organisms to the sediment to be dredged or to an elutriate and then evaluation of the organism response. The type of effects may range from acute mortality to a chronic sublethal effect; the magnitude of response may range from death to no effect. Major limitations on the use of bioassays are that they are usually more difficult, time-consuming, and expensive than chemical analyses.

A total sediment analysis will yield an inventory of the total concentration of chemical constituents, including mineral and nonmineral fractions of a sediment. The results of these analyses will provide some indication of the general chemical similarity or compatibility of the sediments to be dredged with the sediments at the proposed disposal site. However, because chemical constituents are partitioned among various sediment fractions, each with its own mobility and bio-availability, a total sediment analysis is not a useful index of the degree to which dredged material disposal will affect water quality or aquatic organisms.

It is apparent that the complex issue of the potential environmental impacts of dredging/disposal operations must be continually evaluated. Nevertheless, the preceding tests can be

used to indicate what might be expected from any given operation. The test results are not intended to be, nor should they be, interpreted as rigid criteria and/or standards. They represent the current state-of-the-art in ecological evaluation of dredged material discharges and reflect an increasing national concern with the environment in general and, on a more regional basis, of the Chesapeake Bay.

The following tabulation classifies the principal dredge types by mode of operation:

<u>Type</u>	<u>Mode of Operation</u>
Hydraulic dredges	Material conveyed by water through pipe
Pipe Line	No storage — continuous pipe delivery
Plain suction	Nozzle sucks loose sand or mud
Cutterhead	Rotary cutter loosens material for nozzle
Dustpan	Water jets loosen sand for wide flat nozzle
Seagoing Hopper	Drag nozzle feeds hoppers in seagoing vessel
Bucket	Digging bucket manipulated from floating hull
Clamshell	Two-part bucket swung from stiff leg derrick
Orange peel	Three or four-part bucket used on rock or in limited space
Dipper	Rooting bucket on stiff arm
Ladder	Chair of buckets on pivoted arm
Stationary	Mining or gravel producer
Barge loading	Belt conveyor to barges alongside
Seagoing hopper	Hoppers in seagoing vessel

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## REMOTE IN-SITU ELEMENTAL ANALYSIS SYSTEMS FOR UNDERWATER APPLICATION

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### INSTRUMENTAL METHODS

Remote elemental analysis systems for determining planetary composition have been developed by the National Aeronautics and Space Administration (NASA) and used successfully in the Apollo and Viking Programs. A group of investigators from NASA, the University of Maryland, the National Oceanic and Atmospheric Administration (NOAA), the Energy Research and Development Administration (ERDA), and the U.S. Geological Survey (USGS) are now thinking of applying these systems to terrestrial problems. One problem of particular interest to the group is the monitoring and mapping of pollutants such as traces of heavy metals in the Chesapeake Bay region. Because the program is just beginning, only the systems approach, theoretical calculations, and preliminary measurements can be considered.

The design of the experiment systems for remote operation underwater is strongly affected by the instrumental survival requirement in a rather hostile environment and low-power operations. Furthermore, large amounts of data are obtained and must be rapidly processed for use by individuals who have little experience with the experiment apparatus. These are similar to the constraints involved in the development of instrumentation for space-flight operation. The system developed can be considered as consisting of four parts: the excitation source and detector instrument, the data preprocessor section, the data transmission system, and the data analysis and interpretation portion. By separating the system in this way, using distributed intelligence microprocessors and the developing interactive analysis programs, the environmental, power, and data requirements can be achieved.

A neutron gamma-ray method is now being developed to demonstrate the foregoing systems. The excitation source to be used is a machine accelerator using a deuterium/tritium (DT) reaction to produce 14-MeV neutrons. The neutrons excite characteristic gamma-ray emission from the neutron-irradiated surface. The discrete line emission produced can be used to infer both qualitative and quantitative elemental composition. The neutron die-away time can also be used to determine composition. Both NaI(Tl) and Ge(Li) detectors are used to measure the gamma-ray flux, and  $\text{He}^3$  detectors are used to monitor the neutron flux.

A data preprocessor developed at the Goddard Space Flight Center (GSFC) for space-flight application will be used to accumulate, digitize, store, format, and prepare the data for transmission. A major consideration in the development of the preprocessor hardware and software involves the development of programs that will digitize, compact, and accumulate the data so as to prevent degradation of the information content. The data system must also be capable of controlling the operation of the instrument system. The experiment is controlled by commands sent to the data preprocessor. The system is now being updated to include microprocessors that have recently become available.

Data transmission through the data preprocessor can be accomplished by telephone, microwave, and, possibly, by satellite link from remote sites to central data processors. All three methods have been successfully demonstrated during the Geneva Atoms for Peace Conference, the national Telemetry Conferences, and the Apollo-15 and -16 missions.

The final link in the experiment system involves the use of large and small computers at a central data processing complex. The software required for this system has been developed for the X-ray and gamma-ray orbital spectroscopy experiments flown during the Apollo missions. Interactive data analysis programs have been used to analyze the flight data over the past years. Both real-time data analysis and postflight detailed analyses have been carried out. The programs, developed for use on larger computer systems, are now being modified for use on small computers. The approach to be used in the underwater research program will involve analysis of the data in real time or near real time. This requirement arises from the importance of obtaining analyzed results as soon as possible after measurement. The mapping programs also require quick processing of large amounts of data in order to obtain maximum benefit from the programs.

The elements of the total measurement system have been described in the foregoing paragraphs. Each part of the experiment components has been tested, and, in certain cases, overall system capability has been tested. For applications to problems involved in the measurements of pollutant levels and their distribution in the Chesapeake Bay, a number of modifications to the system must be made. The sensitivity of the neutron/gamma-ray source-detector to the expected contaminant levels requires further study. Operations on the surface, underwater, and in submersible units must be developed. The study program has begun, and sufficient work required for demonstrating system feasibility should be completed by the end of this year.

## **PROBLEMS OF UNDERWATER MEASUREMENTS**

A planned development sequence is aimed at performing, by mid-1977, precursor, exploratory, sea-bottom (Chesapeake Bay) analysis or assessments of heavy element pollutants such

as Cd, Pb, and Hg. The following milestones must be reached if a submersible operation by mid-1977 is to be achieved:

- By the end of summer 1976, the NASA neutron generator will be "operational" in the laboratory at GSFC or the University of Maryland. Preparations will then be made to "package" the generator and the requisite detector for underwater use to an operating depth of approximately 122 meters (400 feet). It is hoped that other agencies or groups, such as ERDA and the U.S. Naval Research Laboratory, will cooperate with NOAA/NASA in this endeavor. The packaging will be designed so that the generator/detector assemblies can be lowered from a dock, manipulated by a diver in certain circumstances, or, in particular, mounted on or held by the manipulators of a research submersible. The packaging operation must consider the restricted volume and power pertaining to a submersible. Thus, the associated electronic "boxes" must be engineered to fit a typical submersible. The associated cabling connectors, etc., must also be designed for submersible operations. The designers and packagers must understand the problems peculiar to underwater missions:
  - Restricted visibility
  - Optical viewing distortion
  - Sea-water corrosion
  - Water pressure
  - Often indeterminate interfaces between water and bottoms that are not always hard or firm
  - Ambiguous and fuzzy bottom topography
  - Varying water composition and salinity
  - Position referencing
  - Natural background radioactivity
- Waterproofing and system packaging should be completed by the end of 1976, but with electronics and data gear prepared for land or surface field use only.
- "Swimming pool" tests to approximately 6 meters (20 feet) should begin. Sea-bottom pollutants must be simulated by larding or seeding the pool bottom with insoluble pollutant compounds.
- Pool tests should be completed by early spring 1977. It is possible that an underwater test can be done at the NOAA/Fairleigh-Dickinson University, St. Croix, Virgin Islands, underwater "Hydrolab." This remains to be determined.



- Chesapeake dock-site tests should begin. Submersible compatible engineering packaging must be completed. Accompanying boat tests must also be started. Systems evaluation meetings and user workshops must be held. A submersible must be designated for field trials, and funding and leasing arrangements must be started.
- By early summer 1977, a Chesapeake operations plan and a submersible sector operations plan should be determined. Systems compatibility (with submersible) should be defined, and a submersible lease should be signed, and agency responsibility, data management, etc., defined.
- In summer 1977, a submersible evaluation mission should begin either at or in an area judged to have bottom contaminants. Water-column contaminants from eutrophication should be considered for activation analysis.

The mission duration is expected to be about 1 week.

- In autumn 1977, a review workshop meeting should be held, with wide state, federal, academic, and private (e.g., shellfish harvesters) participation. Efficacy of activation/submersible technology and data results should be evaluated, and future plans should be prepared.

## SUMMARY

Undersea operations pose a variety of problems that demand the attention of individuals and groups familiar with, and experienced in, underwater technology. Submersible operations have limitations of duration/mission (about 6 to 8 hours average) and, as stated previously, space and power restrictions. A submersible usually carries 2 to 3 persons: pilot, copilot, and observer or pilot and two observer/scientists. Some vehicles permit an experimenter/diver to exit or "lock-out" of an aft (separate) compartment and work in the sea at ambient pressure, which would necessitate decompression in a special chamber to prevent "bends."

A typical submersible, battery powered for all electrical needs including propulsion, can be "sailed" or maneuvered at about 10 to 15 meters/s<sup>2</sup> (2 to 3 knots) maximum speed fairly close to and steadily over the bottom, with the observer/scientist operating the two manipulators like extensions of his own arms and hands. Thus, the activation components can be lifted up or plunked down onto or into the bottom sediment at will. Visibility is usually sufficient, even in murky waters, (to 8 meters (25 feet)) to permit visual management. External lights can also be used to illuminate the scene of action.

The submersible can hover in still water for some minutes; any current demands propulsion (i.e., power usage, reducing the submersible's downtime correspondingly). It will be important to learn how to position the radiation emitter and the detector to best advantage



for highest signal-to-noise ratios or strongest absolute signals. The observer or a companion will be required to monitor the electronic equipment in the diver compartment for quick visual (CRT) display. However, tape or other storage will probably be necessary for later readout (but not much later). Position references will have to be included in the data storage.

There is no doubt that a sea-bottom activation-analysis mission can be performed at selected Chesapeake Bay sites. An attendant surface ship will be necessary. The submersible will give quick "spot" pollutant readings with greater accuracy and versatility than surface means can provide. However, if widespread (e.g., more than  $26 \text{ km}^2$  ( $10 \text{ mi}^2$ )) bottom pollution is apparent, the detailed sector scanning will have to be done by and from a surface vessel, perhaps with an activation system mounted on a "sled."

Yet, the submersible will be required to permit the observers to test the gear *in situ* while making changes and noting deficiencies, when necessary. Also, the submersible will act as a "pathfinder" for a surface test vehicle, which will, in the long run, save expensive ship time because the submersible will actually *see* what goes on and will note bottom peculiarities, etc. This cannot be easily done "blind" from the surface.

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## THERMAL DISCHARGES AND THEIR ROLE IN PENDING POWER PLANT REGULATORY DECISIONS

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### ABSTRACT

Federal and state laws require the imminent retrofit of offstream condenser cooling to the newer steam electric stations. Waiver can be granted on the basis of sound experimental data demonstrating that existing once-through cooling will not adversely affect aquatic ecosystems. Conventional methods for monitoring thermal plumes, and some remote sensing alternatives, are reviewed, using ongoing work at one Maryland power plant for illustration.

### INTRODUCTION

One of the more pressing matters confronting operators and regulators of power plants is the 316a procedures promulgated under the National Pollution Discharge Elimination System. These will decide whether the newest and largest existing power plants must be backfitted with cooling towers. Based on current interpretations of criteria, three Maryland steam electric stations (the Calvert Cliffs nuclear plant on the western shore, Chalk Point on the tidal Patuxent, and Morgantown on the Potomac estuary) must install offstream cooling by 1981 unless it can be demonstrated, in accordance with 316a guidelines, that offstream cooling is a more stringent control of thermal pollution than is necessary for the "protection and propagation of balanced indigenous" populations. The issue comes down to a quantification of the tradeoffs between costs (scores of millions for capital and operating, energy penalties due to derating, increased consumptive water use, aesthetics of towers and fogging) and benefits (reduction in thermal loading on estuaries, specifically, temperature stress due to plume entrainment of plankton, possible upsets of fish migratory patterns due to temperature gradients, and warming of local benthic habitats). Environmental monitoring of plant operations must be conducted aggressively because the federally mandated compliance schedule means that tower construction must begin before 1979 if a waiver is not granted.

Remote sensing appears to be promising for answering some of the more difficult questions about the advection and dispersion of heated effluents. Because of this potential niche, we

will concentrate on the thermal plume aspect of the 316a demonstrations, using ongoing work at Calvert Cliffs for illustration (Power Plant Cumulative Environmental Impact Report, 1975). To better appreciate the implications of these studies, we will first trace the evolution of 316a and the way it meshes with state water quality criteria and Environmental Protection Agency (EPA) intake structure (316b) considerations. Throughout, we will try to stress the biological concerns underlying the whole regulatory apparatus (Saila, 1975).

Note that the Power-Plant Siting Program (PPSP) is advisory and has no direct regulatory power. Our charge is to help protect the environment while avoiding undue delay or costs in the supplying of adequate electric power. In the present context, this translates into conducting reliable and decision-oriented impact assessments and making our findings fully available to all of those grappling with power-plant siting and operating problems.

### 316a AND RELATED REGULATIONS

Plants that must make successful 316a demonstrations if they are to obtain variance from cooling tower retrofit include:

- Existing base-loaded steam electric stations constructed after January 1, 1970, and having rated capacities in excess of 500 megawatts electrical (MWe).
- Any existing plant that cannot comply with state water-quality standards.

Table 1 shows that Calvert Cliffs and Morgantown (the two largest Maryland plants in respect to withdrawals) fall under the age and size criteria.\* Chalk Point (third largest plant flow-wise) has requested a 316a variance from state water-quality criteria (sketched in table 2).†

The emergence and implementation of the 316a procedures has not been smooth, and some aspects are still in legal limbo. A first-draft version, circulated more than 2 years ago, would have required almost all power plants to undergo 316a. Response from utilities and local government was heavy, and subsequent versions zeroed in on those plants having the longest remaining life expectancy and heaviest water use. A technical guidance manual issued in draft form called for ecological information of unprecedented scope and detail, but supplied no meaningful scheme for assessing impacts to the sustained yield and stability of ecosystems. Three alternative themes were vaguely suggested:

- Recourse to historical data to show that no significant adverse environmental changes had occurred

\*For information on 316a and 316b, contact Richard Smith, Environmental Protection Agency Region III, Philadelphia, Pennsylvania 19106.

†For Maryland water-quality regulations, contact L. Ramsey, Water Resources Administration, Annapolis, Maryland 21401.

Table 1  
Some Parameters for Operating Maryland Power Plants  
Relating to Aquatic Stress

Utility <sup>a</sup>	Station	Unit Completion Dates	Average Annual Chlorine Use (lb/kW)		Typical Summer Thermal Dose: $D = \Delta T (^{\circ}F)^b \times t \text{ (sec)}^c$			Average Water Flow <sup>d</sup> (cfs) <sup>e</sup>		Average Flow of Receiving Water <sup>f</sup> (cfs) <sup>g</sup>	Receiving Water Body	Profile of Receiving Body (ft) <sup>h</sup>		Discharge Canal	Curtain Wall	Mechanical Cleaning
			1972	1974				With-drawn	Through Condenser			Width	Outfall Depth			
APSCO	R. P. Smith	1923-58	0	0	2,520	8.4	300	125.1	121.1	3141 <sup>h</sup>	Potomac	700	0	X		
B&E	C. P. Crane	1961-63	0	0	16,422	11	1,428	636	636	Tidal	Seneca Cr. (Patapsco)	1,320	1	X		
B&E	Gould St.	1926-52	0.92	0.08	1,277	13.3	96	237	237	Tidal	Patapsco	5,300	4	X		
B&E	Riverside	1942-53	0.45	0.16	2,970	15	198	486	486	Tidal	Patapsco	8,000	8	X		
B&E	H. A. Wagner	1956-72	0.42	0.43	2,496	13	192 (max)	1,471	1,471	Tidal	Patapsco	10,600	#1-6.6 #4-1.5	X		
B&E	Westport	1905-50	0.78	0.04	2,554	13.3	192	353	353	Tidal	Patapsco	2,200	4.5	X		
B&E	Calvert Cliffs	1974-76	—	0	2,400	10	240	2,754	2,754 (one unit)	Tidal	Ches. Bay	26,400	20	(j)	X	X
Delmarva	Vienna	1928-71	0	0.08	NA	12	NA	130	124	Tidal	Nanticoke	1,000	15	X		
PEPCO	Brenning Rd.	1906-72	0.1	0.14	NA	#10-12: 10 #13-17: #15-16: 24 <sup>d</sup>	NA	266	520.1	Tidal	Anacostia	NA	2			
PEPCO	Buzzard Point	1933-45	0.004	0.09	NA	10	NA	155	155	Tidal	Anacostia	NA	NA			
PEPCO	Chalk Point	1964-65	1.02	1.20	79,200	11	7,200	871	696	Tidal	Patuxent	6,200	NA	X		
PEPCO	Dickerson	1959-62	0.13	0.06	4,800	16	300	584	553	9810 <sup>h</sup>	Potomac	600	8	X		(j)
PEPCO	Morgantown	1970-71	0.44	0.26	24,000	10	2,400	2,229	2,222	Tidal	Potomac	10,000	20	X	X	X
PEPCO	Potomac River	1949-57	0.29	0.23	NA	14	NA	520	518	Tidal	Potomac	NA	NA			
VEPCO	Potomac Point	1948-62	0	0	6,278	14.6	430	522	522	Tidal	Potomac	NA	2			

Source of data (except for columns labeled "Typical Summer Dose," "Curtain Wall," and "Mech. Cleaning") = "Steam-Electric Plant Air and Water Quality Control Data for the year ended December 31, 1974, for each utility, as reported to the Federal Power Commission and the 1972 chlorination data, which was obtained from Power Plant Environmental Impact Report No. PPSP-CEIR-1, Maryland Power Plant Siting Program, 1973.  $\Delta T (^{\circ}F)^b$  = average temperature rise over condenser for 1974 as reported for each plant to the FPC except for Chalk Point, Dickerson, Morgantown, and Calvert Cliffs where design temperature rises are used.  $\Delta T$ 's for Brenning Road, Buzzard Point, and Potomac River from PEPCO. Calvert Cliffs data from B&E.

<sup>a</sup>APSCO = Allegheny Power Service Corporation; B&E = Baltimore Gas and Electric Company; Delmarva = Delmarva Power and Light Company; PEPCO = Potomac Electric Power Company; VEPCO = Virginia Electric and Power Company.

<sup>b</sup>K = (5/9) ( $^{\circ}F$  + 459.67)

<sup>c</sup>Includes retention time in effluent canals.

<sup>d</sup>Once-through cooling systems, with the exceptions of Vienna and Brenning Road, that use mechanical draft cooling towers for 61 and 72 percent, respectively, of their generation.

<sup>e</sup> $m^3/s = ft^3/s \times 2.832 \times 10^{-2}$

<sup>f</sup>The flushing rates (and biological regeneration times) of tidal, stratified systems are currently being investigated. This is important to know because the relative effect on an ecosystem depends upon the percentage of natural flow taken into the power plant.

<sup>g</sup>Stress = feet  $\times$  3.048  $\times$  10<sup>-1</sup>

<sup>h</sup>Source of data: Patrick N. Walker, "Flow Characteristics of Maryland Streams," Maryland Geological Survey, Report of Investigations, No. 16, (1971).

<sup>i</sup>Discharge tunnel

<sup>j</sup>Dickerson has ability to backflush online.

- Engineering and scaling arguments demonstrating that stress profiles were acceptably small
- Biological monitoring to directly demonstrate the absence of appreciable impact

The view taken by the state is that all three types of information should be mustered to give a consistent evaluation of impact. Review comments prompted revision of the guidelines, which is still ongoing. No Maryland plants (and fewer than half those nationwide) had undergone 316a determinations before a recent ruling in the Fourth District Court remanded 316a to EPA for further redrafting with regard to (among other things) requirements for salt and brackish water cooling towers.

Table 2  
Criteria for Discharges into Maryland Tidal Waters

Criteria	Comment
a. The discharge flow shall not exceed 20 percent of annual average net flow past the point of discharge that is available for dilution.	Relates to probability for plume entrainment, cooling system entrainment, or screen impingement.
b. The 24-hour average of the maximum radial dimension measured from the point of discharge to the boundary of the full-power $\Delta T = 2^\circ \text{K}$ isotherm above ambient (measured during the critical periods) shall not exceed one-half of the average ebb tidal excursion.	Prompted by concern that the extent of meroplankton habitat modification might be of estuarine scale.
c. The 24-hour average full-power $\Delta T = 2^\circ \text{K}$ thermal barrier above ambient (measured during the critical periods) shall not exceed 50 percent of the accessible cross section of the receiving water body, both cross sections taken in the same plane.	Desire to maintain routes free of temperature gradients that might block fish migration, either by attraction or avoidance.
d. The area of the bottom touched by waters heated $\Delta T = 2^\circ \text{K}$ or more above ambient at full power shall not exceed 5 percent of the bottom below the average ebb tidal excursion; both areas to be measured during the critical period.	Pertains to the regional sizing of benthic habitat modification.

Despite its inauspicious record on tidal waters, the focus of 316a is clearly to obtain definitive assessments of impacts to aquatic populations. This, rather than water quality *per se*, is also the goal of recently promulgated Maryland water-quality regulations that are tied to 316a as mentioned previously.

Some of the state criteria that gate 316a studies are given in table 2, which also shows the ecological concerns underlying the thermal-plume criteria. Criteria b through d refer to a 2-K (2°-C) (excess of discharge with respect to ambient) isotherm, which is equal to factors of 2.5 to 5 dilution for plants on brackish Maryland waters. For turbulent, high-velocity discharges, such dilutions are attained within the "near field" where the shape and extent of the thermal plume tend to be momentum dominated. For sluggish discharges into bodies in which the rates of cooling flow and nontidal ambient flow are similar, monitoring must be extended into the "intermediate" field in which tide, wind, and bottom topography have comparable influence on plume dispersion and advection. (A discussion of the instrumental implications of monitoring in these two regimes and a recently encountered need to track a plume out to factor-of-ten greater dilutions will follow.) Although no field work is easy to do well, measurements of plume extent for water quality (WQ) criteria are much less taxing than the biological monitoring in patchy estuarine environments that would directly test biological concerns (sketched in table 2) to see if more exhaustive work was warranted. The (older) plants that satisfy these WQ criteria are exempt from further demonstration. Those that do not must either make a successful 316a demonstration (typically involving 1 to 2 years of intensive and comprehensive biological sampling) to obtain site-specific variance from the water-quality regulations or retrofit cooling towers.

At the risk of courting utter bewilderment, we mention that there are also 316b procedures for assessing the impact of intake structures and the nonthermal component (mechanical, biocidal) of in-plant stress. These investigations, which all major Maryland plants will undergo, came into being later than 316a and reflect a belated awareness that thermal pollution is not the only, or in some cases the major, source of power-plant stress. Because our concentration is on thermal discharges, it will suffice here merely to mention that 316a and 316b considerations are coupled by the conservation of heat:

$$H \approx c * \Delta T * q$$

The population that risks mechanical damage during entrainment (proportional to flow  $q$ ) is inversely related to the condenser temperature rise,  $\Delta T$ , which in turn determines thermal-plume size and gradients.

Having touched on the regulatory framework to which we must respond, we now review some of the ground-based and remote methods for mapping thermal plumes.



## THERMAL-PLUME MAPPING

### Near Field

Plume mixing in the turbulent outfalls typical of most Maryland plants rapidly quenches excess temperatures. Dilutions of factors 2.5 to 5 (appropriate of the  $\Delta T = 2$  K isotherm specified in WQ criteria c through d, table 2) or of factors of 5 to 10 that reduce excess temperatures to the level of ambient thermal jitter (0.5 to 1 K near surface and more at depth) in shallow estuaries, usually are obtained by the time the effluent has moved distances equal to 10-to-50 outfall-structure diameters. The time spent in the plume is a few minutes, which is short compared to a tidal period or to the duration of mapping runs by vessels rapidly transecting in the compact plume area (usually less than 100 acres in a 1-K excess T isotherm). Although plumes may either float or sink depending on the relative steepness of vertical temperature and salinity gradients, in this part of the Chesapeake, nonfloating plumes are the rule.

A number of techniques will suffice for near-field monitoring. Mathematical and physical simulations provide qualitative guidance on the shape and direction of the effluent ("Surface Thermal Plumes: Evaluation of Mathematical Models for the Near and Complete Field," Vols. I and III, 1975). Although this information is useful for planning initial sampling strategies, such models should not be relied on for plume-size information in tidal situations in which differences between salinity and temperatures of intake (drawn primarily from deep layers) and receiving (shallow, near-shore) waters are critical.

Perhaps the most straightforward ground-based technique is to sample with thermistors at various depths. Arrays can be either towed through the plume or deployed in a dense grid. Towing requires people and boat time, and precise location is difficult to find. Many station grids are expensive to buy and maintain. Sensitivity in both cases is limited by ambient patchiness.

Releasing dye in the plant and sampling with fluorometers is another conventional method. Because plume sampling with pumps involves long response time, it drastically prolongs cruises. Use of towable fluorometers is a recent improvement (Carter, 1974; Measures et al., 1975; "Forecasting Power Plant Effects on the Coastal Zone," 1976; and Keys and Hokheimer, 1974) that offers enhanced signal-to-noise ratios (although interference from the fluorescence of phytoplankton can be troublesome). Remote sensing of dye from a slow-moving airborne platform is an alternative, but can present problems associated with bad weather or precise location. Costs of acquiring ground truth remain. Therefore, remote means of near-field sampling may not provide clear advantages over boat surveys.

Although infrared (IR) imagery is sensitive, it is hampered by the nonfloating nature of estuarine plumes and by ambient thermal patchiness. Ground truth must include not only the customary radiometry, but also extensive temperature profiling with depth. In effect, IR remote sensing becomes an adjunct of the ground-based sampling program.



### Intermediate Field

The two reasons for intermediate field monitoring are:

- To test for compliance with state WQ criteria (b through d, table 2) in the relatively few situations where ambient freshwater flow is similar to, or only a fewfold greater than cooling flows, and to dilutions of  $\Delta T = 2$  K that are not attained near the out-fall.
- Well-mixed situations in which one wishes to follow the history of the plume beyond dilutions of 10 (corresponding to plume ages of one to several tidal cycles) to determine possible dispersion of long-lived biocides (chloramines or leached copper), to learn the fate of waters from which some biota have been cropped during plant entrainment, or to demonstrate freedom from appreciable plant influence of biological sampling stations intended as controls in spatial gradient comparisons of population size, condition, or composition.

In the first instance, thermal signals are comparable to those in near-field work, and similar instrumental considerations apply. However, the monitoring tends to be more arduous because the plume may hug the shoreline at one time and spread in a thin lens at another, depending on the interplay of tide, wind, runoff, and vertical structure, necessitating monitoring for the many permutations of these driving factors.

Intermediate field mapping of well-diluted plumes is a realm exclusively for either ground-based or remote fluorometry, because other methods lack the requisite sensitivity or signal-to-noise ratios (Carter, 1974; Measures et al., 1975; "Forecasting Power Plant Effects on the Coastal Zone," 1976; and Keys and Hokheimer, 1974). It remains to be seen at what dilutions remote fluorometry will be limited by turbidity. A dump from the state's data files on Secchi disk data of record discloses extremes of 0.5 to 20 meters, with typical observations for the Chesapeake between the Bay Bridge and Point Lookout ranging between 1 and 3 meters.

### AN ILLUSTRATION: CALVERT CLIFFS

Most PPSP thermal-plume mapping to date has been done at Calvert Cliffs ("Summary of Current Findings: Calvert Cliffs Nuclear Power Plant Aquatic Monitoring Program," 1977). The design of this plant dates from the late 1960's, when the potential impact of thermal pollution was of paramount concern (while in-plant mechanical damage received relatively little attention). A large withdrawal rate of  $76.4 \text{ m}^3/\text{s}$  ( $2700 \text{ ft}^3/\text{s}$ ) for each of the two 845-MWe units) was adopted to reduce  $\Delta T$  to a maximum of 5 K ( $5^\circ\text{C}$ ). Although this flow exceeds that of most of the Chesapeake's tributaries, according to Pritchard's calculations,\* it equals approximately 6 percent of the freshwater flow past this section of the Bay. The plant sits

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\*From "Nuclear Power in Maryland," Governor's Task Force on Nuclear Power Plants, Annapolis, Maryland, December 1969.

flush with the shoreline, and water is drawn from a dredged channel extending out to the 40-foot contour. The outfall is a submerged diffuser with a 3 m/s exit velocity that induces rapid mixing.

The field program we describe was performed by Martin Marietta Laboratories and the Chesapeake Biological Laboratories (CBL). Results are pooled and integrated with findings of the Baltimore Gas and Electric Company (BG&E) work funded by the Energy Research and Development Administration (ERDA). Data and interpretations are supplied to Maryland Water Resources Administration for 316a consideration and to EPA and the Nuclear Regulatory Commission (NRC).

Two kinds of near-field plume mapping were done during the first year (unit 1) of operation: (1) towed-thermistor surveys to define the plume behavior as a function of water-column condition (stratified and well-mixed) and tidal stage (slack, ebb, and flood), and (2) deployment of time integrating (week sampling duration) chemical thermometers to assess benthic habitat modification in the area swept by the plume.

Figure 1 is a plan view showing the general layout and indicating how towed thermistor strings cut the plume. A string normally records at three depths; 0.5, 3, and 6 meters (near bottom), but is shortened for sampling in the shoals northeast of the outfall. The lettered points are anchored buoys positioned by RAYDIST with accuracies of  $\pm 3$  meters. The survey vessel maintains constant speed between these reference points. This monitoring pattern cuts the plume at right angles, recording profiles from wing to wing and out longitudinally to where the centerline signal is indistinguishable in ambient patchiness. Measurement programs of 3 to 5 days duration to obtain replication for all tidal cycles were run in the early spring (Bay well-mixed), late summer (stratified), and fall (stratification breakup).

Sample near-field results from a typical winter run at ebb tide are shown in figure 2. Although isothermal contours are displayed as measured, a little mental arithmetic will convert them to plots of excess temperature ( $289.7\text{ K}$  ( $16.6^\circ\text{C}$ )) being ambient at all depths in this well-mixed situation). The plume, here spreading uniformly at all depths, is depicted in sufficient detail for our purposes, namely:

- To estimate the thermal dose experienced by plume-entrained plankton
- Together with synchronous biological data (trawls, gill nets, dredges, and sonar scans), to test for modification in fish (migratory arrest of transients and plume entrapment of resident species) and crab (increased winter susceptibility to predation) behavior
- To relate the range of perceptible thermal influence to Bay dimensions

For the benefit of those who note that the ebbing tide drags the plume over the intake channel, pumped-dye and flow-meter studies by Chesapeake Bay Institute (CBI), Johns Hopkins University, found recirculation to be less than 10 percent.

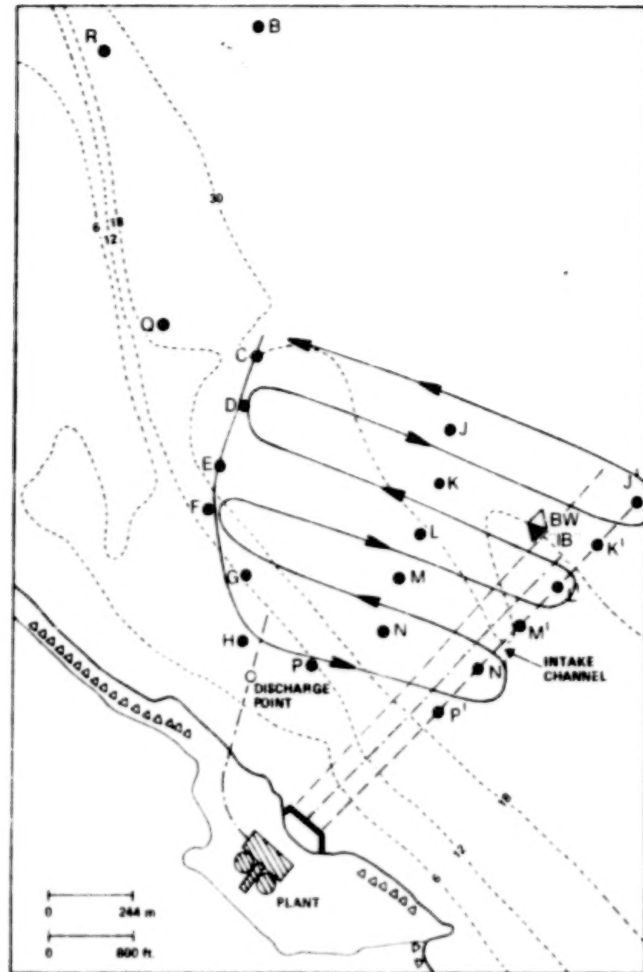


Figure 1. Plan view, showing pertinent Calvert Cliffs plant features and local bathymetry and indicating the path of a typical thermistor scan of the effluent plume.

Although effluent velocities quickly sweep free-swimming organisms out of the plume, nearby benthic communities experience a long-term warming. Time-averaged dose was measured with an array of chemical thermometers. The arrangement is of appealing simplicity (figure 3). The tethered plastic bottles contain buffered sugar-acid solutions whose rate of optical rotation is temperature dependent. Relative exposures are read with a polariscope, and the array is referenced against a recording thermistor.

Both methods of near-field monitoring have demonstrated adequate reliability and cost-effectiveness and will be employed again later this year when units 1 and 2 come on line together. No intermediate field mapping was contemplated because it is clear that:

- Even with two units, the perceptible thermal plume was small in comparison with Bay dimensions.

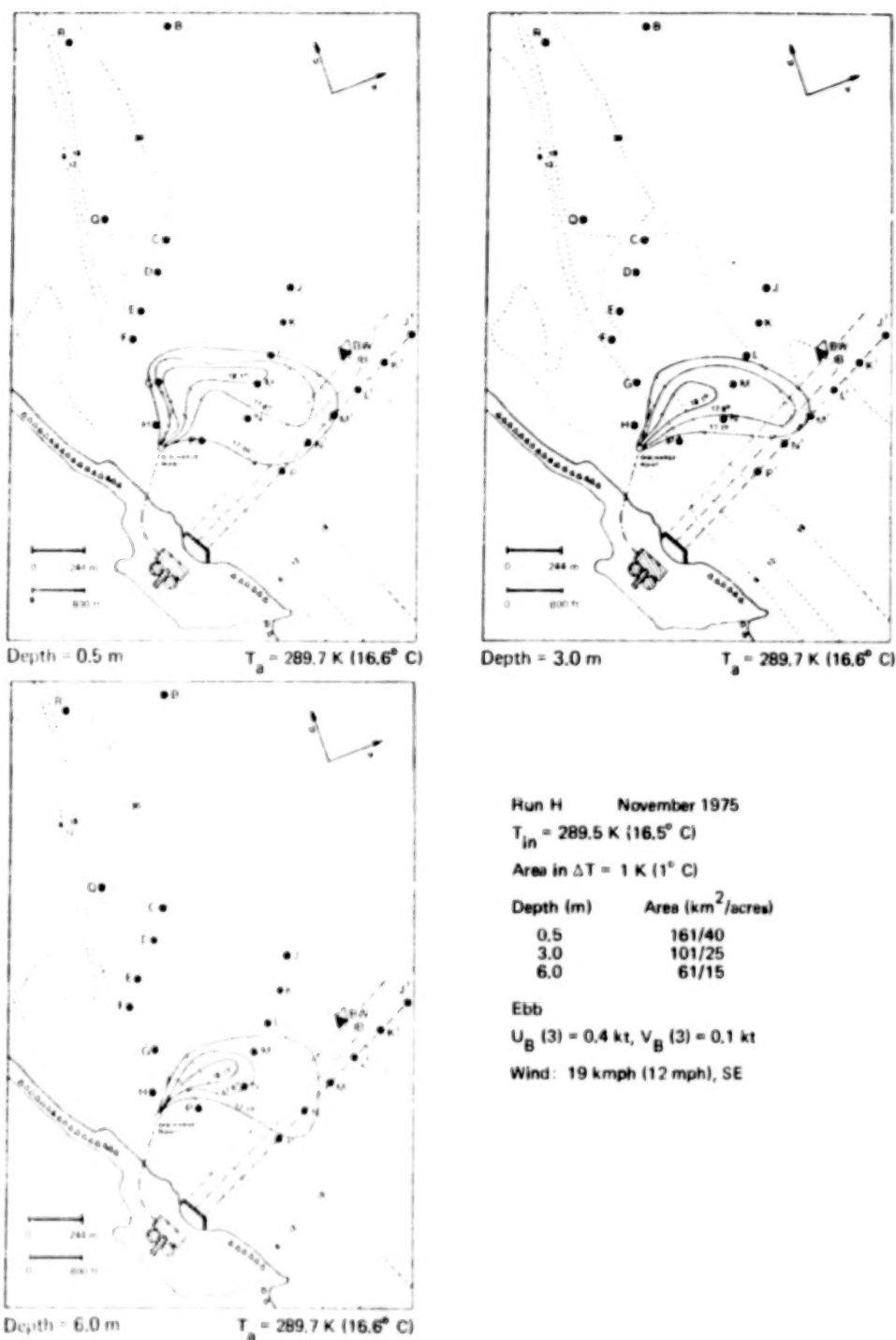


Figure 2. Three-depth thermal maps of near-field effluent behavior. These thermister data are representative of one-unit operation during ebb tide when the Bay is well-mixed.

- Because no chlorine is used in the main cooling system, questions of chloramine transport do not arise.
- No copper enrichment of sediments or oysters was detectable in samples near the plant, obviating the need to look further out.

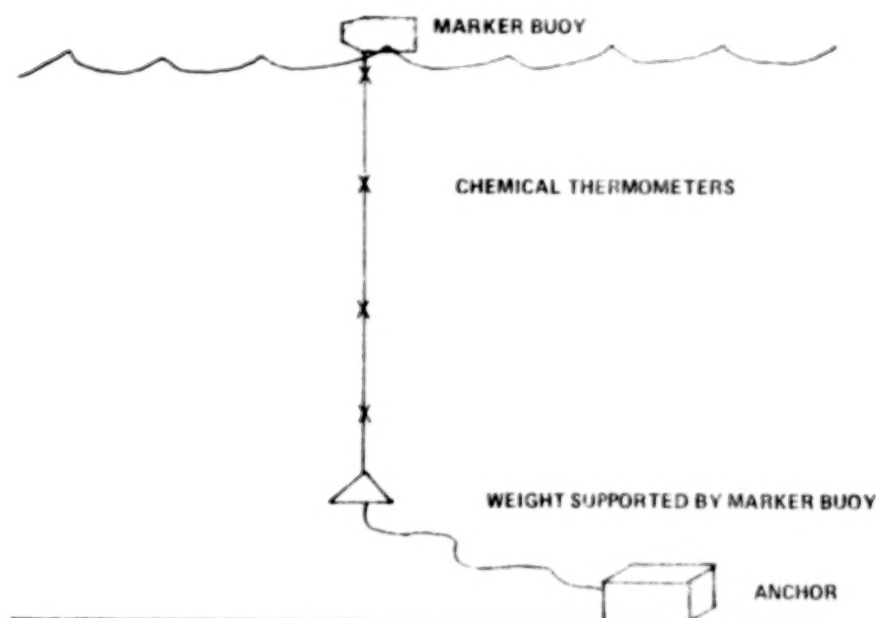


Figure 3. Schematic of the arrangement for profiling the water column with time-integrating chemical thermometers. This rugged and inexpensive gear was developed by the National Oceanic and Atmospheric Administration.

Analysis of the first year's zooplankton data changed our appraisal. Heinle (1977) found that densities of the dominant warm weather copepod, *acartia tonsa*, were dramatically lower than during any preoperational year of record. This scarcity of *acartia* was also found near the outfall (station IIA in figure 4) and at Long Beach (I-A) and Rocky Point (III-A) – stations located a tidal excursion distant to serve as essentially unstressed environments (controls) for biological spatial-gradient comparisons with the plant site. Paired intake/outfall sampling has shown that characteristically 18 to 30 percent of entrained zooplankton are destroyed by mechanical damage in the plant. Near-field thermal mapping has demonstrated that factor-of-5 dilutions are achieved within the shaded area shown on figure 4, indicating that even with dispersionless advection, the plant could not be responsible for station I-A or III-A depletions in excess of ~6 percent. Some PPSP investigators argue that this picture is simplistic and that perhaps these regions do not fully participate in Bay flushing: that repeated nonimmediate recirculation, or some unspecified mechanism associated with plant operations, may be causing the depletion. Others hold that the 1975 zooplankton sag is just one more manifestation of the annual variability of estuarine communities.

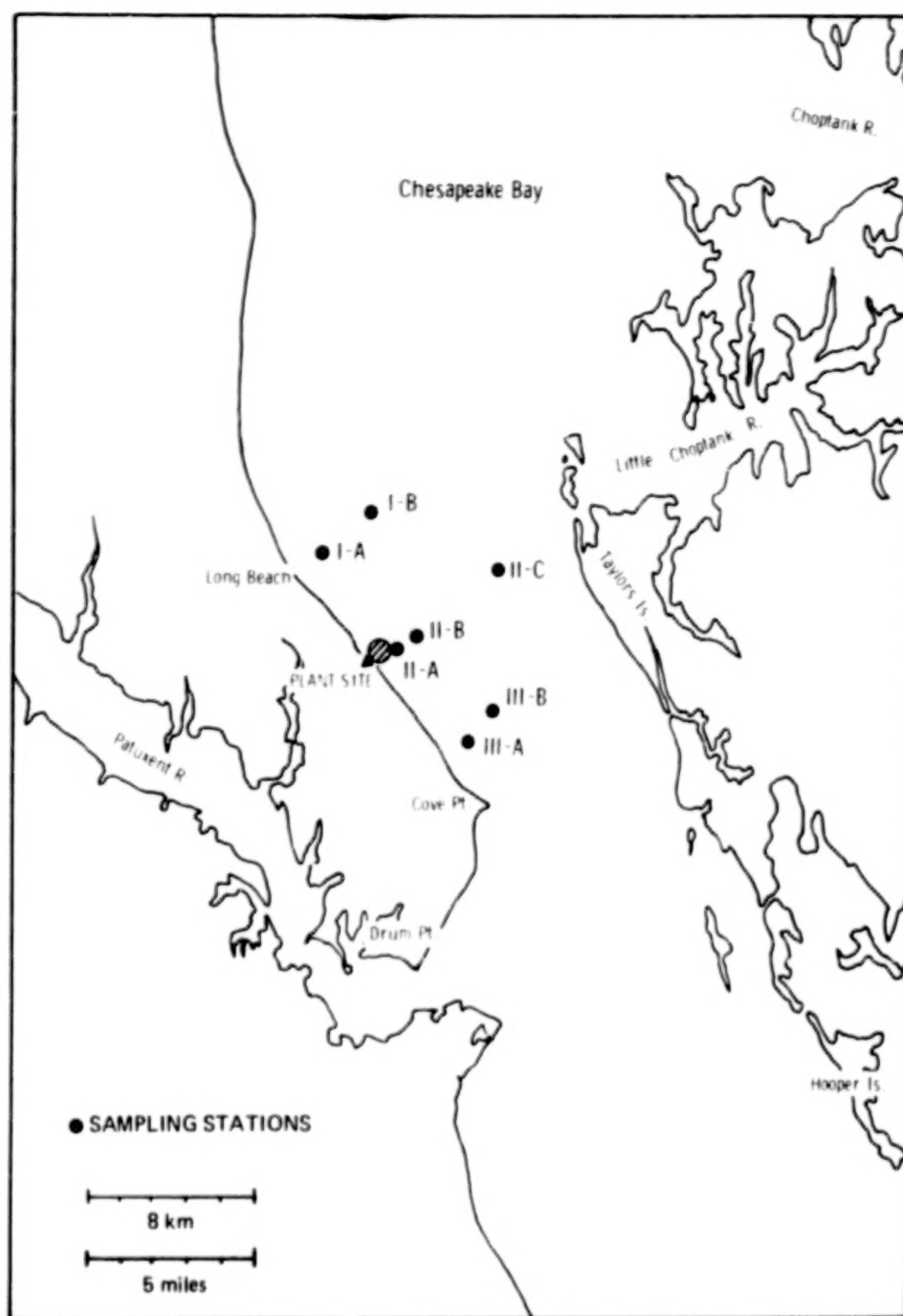


Figure 4. Primary sampling stations for obtaining spatial gradients of biological parameters. Station II feels the near-field plume, and Stations I and III are a tidal excursion removed. Suffixes denote similar water depths (II-C is a channel station). For scaling perspective, the region subject to 1-K ( $1^{\circ}\text{C}$ ) excess temperatures is shaded.

Two steps will be taken to obtain more definitive answers: (1) additional stations will be used this year to extend the sampling further upstream and downstream and (2) intermediate-field plume monitoring will be used in an attempt to document the movement of effluent water over at least one tidal cycle.

Figure 5 shows the plans now being explored with the National Aeronautics and Space Administration/Wallops Flight Center. Steady-state injection (at least 3 days continuous) of rhodamine B will be made in-plant. Three vessels, each towing 3-fluorometers to sample surface, mid-depth, and bottom, will cruise continuously on the closed paths indicated. A remote sensing aircraft, whose lidar and detectors are tuned to the dye, will make repeated overhead longshore passes during which the lidar's search pattern will describe a swath suitable for synoptic interpretation.

Several factors prompt us to plan an ambitious ground-based survey in synchrony with lidar overflights:

- Data from towed instruments provides backup in case any bugs appear in the lidar—an essential for the state in as much as 316a decisions have a fixed deadline.
- The ground-based fluorometry can profile depth with good resolution. These data also will permit the lidar to operate in a depth-integrating mode with increased sensitivity.
- The lidar is intended to provide a continuous record of the plume, and sensitivity permitting (a matter Dan Hickman of the University of Maryland is examining), perhaps to track plume movement beyond the range of the discrete ground truth data.
- Ready comparison of the collecting efficiency and accuracy of the two methods can be made.

Two efforts nominally 3 to 5 days duration each are now contemplated:

- Late Summer (1977)
  - Observe plume when the Bay is in a stratified condition.
  - This is the time of severest natural thermal stress.
  - Water clarity tends to be low, possibly limiting capabilities.
  - Sea state tends to be less rough.
- Winter (1977-78)
  - Observe plume when Bay is well-mixed.
  - Water clarity is high, permitting more sensitivity because of water-column integration by lidar, and background is lower because of reduced phytoplankton fluorescence.

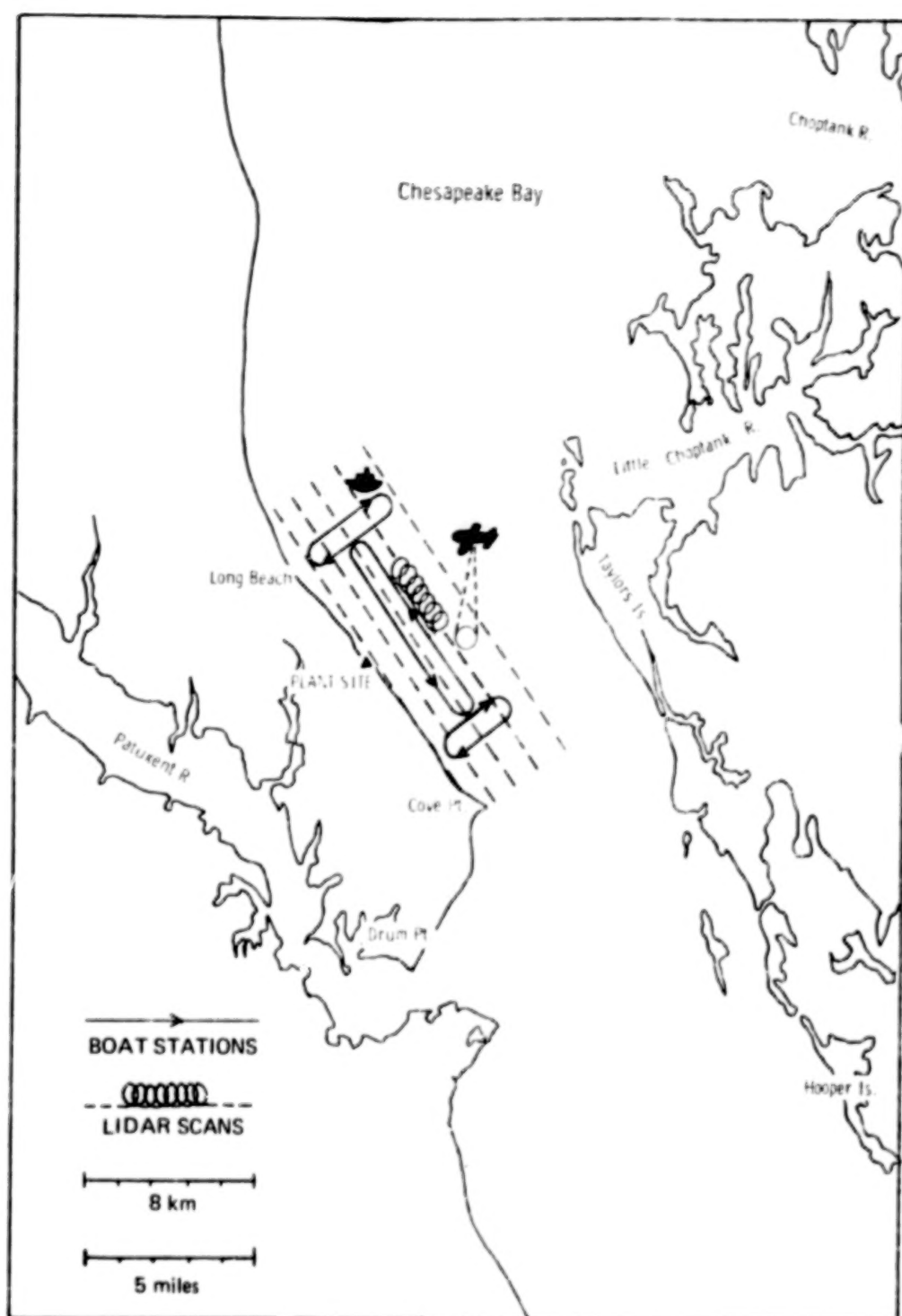


Figure 5. Strategy for synchronous ground-based and remote fluorometry to determine intermediate-field advection and dispersion of the effluent plume.



- Weather can be hard on boat crews and some days may be scrubbed.
- Experience gained during the late summer work can be used to refine the winter effort.

## DESIDERATA

Lead times being what they are (in lining up funding, debugging, and orchestrating field work), the 1979 effective deadline for completing 3163 work looms close. Those who entertain plans to do power-plant related remote sensing are advised to move fast if their results are to have bearing on the pending industry-wide decisions.

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## WORK ON POWER-PLANT (AIR) PLUMES INVOLVING REMOTE SENSING OF SO<sub>2</sub>

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### ABSTRACT

Since 1972, Environmental Measurements, Inc., has been engaged in the acquisition of air-quality and concurrent meteorological data to serve the dispersion model development and plant siting needs of the Maryland Power-Plant Siting Program. One of the major instruments in these studies is the Barringer correlation spectrometer, a remote sensor using atmospherically scattered sunlight that is used to measure the total amount of SO<sub>2</sub> in a cross-section of the plume. The correlation spectrometer and its role in this measurement program are described.

### INTRODUCTION

Since 1972, Environmental Measurements, Inc. (EMI) has been under contract to the Maryland Power-Plant Siting Program (PPSP) and has been responsible for acquiring air-quality and concurrent meteorological data to serve the needs of the program. A remote sensing Barringer correlation spectrometer (COSPEC) that measures both SO<sub>2</sub> and NO<sub>2</sub> has been an integral part of the measurement program. This paper describes EMI's measurement activities in supporting the PPSP and, in particular, the role that the COSPEC has played in carrying out the measurement program.

Among other duties, the PPSP is responsible for two types of activity requiring air-quality measurements. The first of these is dispersion model development with the purpose of advancing the state-of-the-art of air-quality modeling using data from studies of Maryland power plants. These model-development activities have been carried out primarily by Dr. Jeff Weil of the Martin-Marietta Laboratories. The second activity is site evaluation for either power-plant expansion or new construction when a public utility requests permission to build additional generating facilities. A site-evaluation study is then conducted to determine the environmental impact of the proposed construction. In cases of proposed expansion, a plant already exists at the site, and hence an excellent way of determining the potential effect of the expansion is to study the impact of the existing plant. Studies of this nature have been carried out in the vicinities of the Baltimore Gas and Electric Company's (BG&E)

Wagner Power Plant in Baltimore Harbor and the Potomac Electric Power Company's (PEPCO) Dickerson Power Plant on the Potomac River in Montgomery County, northwest of Washington, D.C. In cases of proposed new construction, the impact of a similar plant situated in a similar topographical location is studied (if such exists). This type of study has been carried out on small plants at Easton and Perryman, both in Maryland. The data from these studies have been turned over to the Johns Hopkins University Applied Physics Laboratory, which uses them in its analysis of impact; the results are then reported to the PPSP. EMI has carried out a number of detailed air-quality and meteorological studies to provide data for these two PPSP areas of concern.

In its studies of the effect of fossil-fuel power plants on the air quality of the State, the PPSP has chosen  $\text{SO}_2$  as the major target molecule of interest for a number of reasons. First, there are federal ambient standards relating to  $\text{SO}_2$ . Second, fast-responding instrumentation suitable for field use that can measure  $\text{SO}_2$  in the ambient concentrations typically found as a result of power-plant plume touchdowns is available. Third,  $\text{SO}_2$  is a molecule that is reasonably conserved as it proceeds downwind, at least over the periods of time (several hours) in question in these studies.

One of the main components of the system developed for carrying out these air-quality measurements is the COSPEC. This dual-channel instrument is a remote sensor of  $\text{SO}_2$  and  $\text{NO}_2$  molecules. As used in the PPSP, it is a passive detector using atmospherically scattered sunlight as the radiation source. It is an instrument with a fast time response that is lightweight and has low power requirements. Data gathered by the COSPEC have been used both for dispersion modeling development and for measurements of  $\text{SO}_2$  mass flow.

### COSPEC OPERATION

The Barringer COSPEC is a remote sensor of  $\text{SO}_2$  and  $\text{NO}_2$ . It is a passive detector that, in our applications, utilizes atmospherically scattered sunlight as the radiation source. The remainder of this section is a brief outline of the instrument's operation. Newcomb and Millan (1970) have given a detailed treatment of the theory and operation of the COSPEC.

The COSPEC views the atmospherically scattered sunlight entering the entrance slit of the instrument. This light is contained in a solid angle ( $1^\circ$  by  $1^\circ$ ) centered on the instrument's line of sight.  $\text{SO}_2$  molecules have a number of distinctive absorption bands in the ultraviolet portion of the spectrum. As the scattered sky light proceeds through the atmosphere along the COSPEC's line of sight, the light in these bands will be absorbed by the  $\text{SO}_2$  molecules that may be in solid viewing angle. This light is dispersed by a diffraction grating, and, through the use of a correlation mask on a rotating disk, the amount of radiation in the absorption bands can be compared to the amount of radiation in the portions of the spectrum immediately adjacent to these bands. The difference between these quantities is a direct measure of the total amount of  $\text{SO}_2$  in the line-of-sight path of the instrument. Instrumental electronics convert this difference into a dc signal that can then be displayed on a chart

recorder or on any other desired recording medium. The magnitude of this output signal is proportional to the integrated concentration times path length of  $\text{SO}_2$  (measured in ppm-meters) in the line of sight of the instrument. In other words, it is essentially the total amount of  $\text{SO}_2$  in the line of sight. The instrumental response is linear in the range 0 to (approximately) 750 ppm-meters and begins to depart slowly from linearity above this value. Values typically seen in traversing under power-plant  $\text{SO}_2$  plumes are typically of the order of several hundred ppm-meters.

In physical terms the instrument is well suited to this mobile application. It is relatively small (71 by 30 by 43 cm; 28 by 12 by 17 inches), weighs approximately 18 kg (40 lbs), and requires only 18 watts of 60-cycle ac power. It is mounted on vibration isolators and is designed to operate in an ambient temperature range of 255 to 322 K ( $0^\circ$  to  $120^\circ$  F).

Calibration of the instrument is carried out through the use of quartz cells containing known amounts of  $\text{SO}_2$  that are inserted into the instrument's line of sight. The value of  $\text{SO}_2$  in these cells is certified by the manufacturer. The cells are mounted internally so that turning a knob is all that is required to place them into the instrumental line of sight and to remove them. As a result, each calibration takes less than 1 minute and can therefore be easily carried out as often as desired throughout the course of the measurement day.

## MEASUREMENT METHODS

The classical method of gathering air-quality data to study the air quality of a particular area has been to set out a number of fixed monitors and to measure the temporal variation of the selected pollutants at each monitoring site over extended periods of time. This method has advantages, especially for gathering data to be used primarily for regulatory purposes, because regulations are framed in terms of concentrations measured over a specified period of time at a fixed point. Because PPSP air-quality monitoring requirements are directed primarily toward acquiring data for model development, however, a new method of data acquisition was evolved. The central objective behind this evolution was to be able to go to where the plume is touching down on a given day, to track it, and to measure its impact as it moves around because of changing meteorological conditions. This objective necessitated a change from the classical approach to an essentially mobile approach in which the monitoring instruments are mounted on a moving platform that can track the plume and perform measurements while the platform is actually moving. This led to the development of the Air-Quality Moving Laboratory (AQML). Basically, the AQML is a vehicle in which the monitors are mounted together with the required power-generating, recording, navigation, and support equipment so that they can be easily transported to the area of the plume and can measure the plume in real time while the vehicle is in motion.

The overall measurement program is designed to produce measurements of both the pollutant being studied ( $\text{SO}_2$ ) and, concurrently, the physical state of the atmosphere into which the plume is being emitted. The remainder of this section describes the way in which these measurements are performed.

### **Meteorological Measurements**

For the purpose of carrying out dispersion-model development studies, the physical state of the atmosphere into which the plume is being emitted must be measured. More specifically, information on the wind-velocity profile as a function of altitude and information relating to atmospheric turbulence are needed to determine model parameters. Wind-velocity profiles are obtained by a standard technique of tracking pilot balloons (pibals). This technique simply involves releasing a balloon and tracking its position during its ascent with a theodolite that can measure azimuth and elevation angles. The theodolite tracking data permits computation of wind speed and direction as a function of altitude. This basic technique has been expanded in the PPSP program to the use of two theodolites at the ends of a 1-km base line simultaneously tracking the balloon during its ascent. PPSP studies have shown that this technique is more accurate. The extra personnel required for acquiring the field data and for carrying out the data reduction are justified in terms of the increased accuracy of the resulting profiles.

Atmospheric turbulence parameters are not measured directly, but are inferred from measurements of temperature profiles (i.e., atmospheric temperature is a function of altitude). These profiles have been measured in a variety of ways. The present system employs a small, disposable temperature sonde that uses a thermistor to sense temperature and telemeter it to a ground station by radio. These sondes are simply attached to pibals and flown as often as is deemed necessary (typically three times per day). Obtaining data with these disposable sondes has advantages over some other temperature-profile measurement systems; namely, profile information is obtained from ground level, and the sondes can be flown in high wind or storm conditions.

### **Air-Quality Measurements**

The strategy for obtaining air-quality data downwind of a fossil-fuel power plant with the AQMI follows.

Initially the laboratory proceeds to the site of the target plant to obtain precise knowledge of plume direction. A road downwind of, and fairly close to, the plant is selected for the first set of traverses. The chief criterion in selecting this road is that it be reasonably perpendicular to the centerline of the plume.

A set of four-to-eight successive traverses is made on this road. Each traverse consists of driving completely through and under the plume, starting from a clean air condition on one side of the plume and going completely through the plume to clean air on the other side (i.e., background-to-background). During the course of the traverse, the total overhead burdens of  $\text{SO}_2$  and  $\text{NO}_2$  are sensed by the COSPEC while the concentration of sulfur at ground level is sensed by a Meloy flame-photometric total-sulfur monitor. Analog signals from both of these instruments are recorded along with geographical location and time information



so that the air-quality information for the traverse can ultimately be presented as a precise function of space and time for further analysis.

During the course of the measurement day, several sets of traverses are obtained at different distances downwind of the plant. Simultaneously, the meteorological measurements described above are carried out throughout the day.

The speed of the moving laboratory is adjusted to match the response time of the sensing instruments to the expected pollutant gradients. Within 2 to 3 km of a power plant, where the plume is narrow and the overhead burden gradient transverse to the plume axis is large, the AQML is driven slowly (20 to 25 mph) to improve the resolution of narrow-plume parameters. At distances greater than 5 to 10 km from a power plant, where the plume is broader and the pollutant gradients are smaller, the speed of the AQML is increased without significant loss in data resolution. At the farthest radii, maximum speeds of 50 to 60 mph are used. The choice of speed for each given distance downwind is a compromise between: (1) the desire to traverse the plume quickly so that the plume does not change during the course of the traverse (i.e., so that one obtains a "snapshot" of the plume), and (2) the non-zero response times of the instruments.

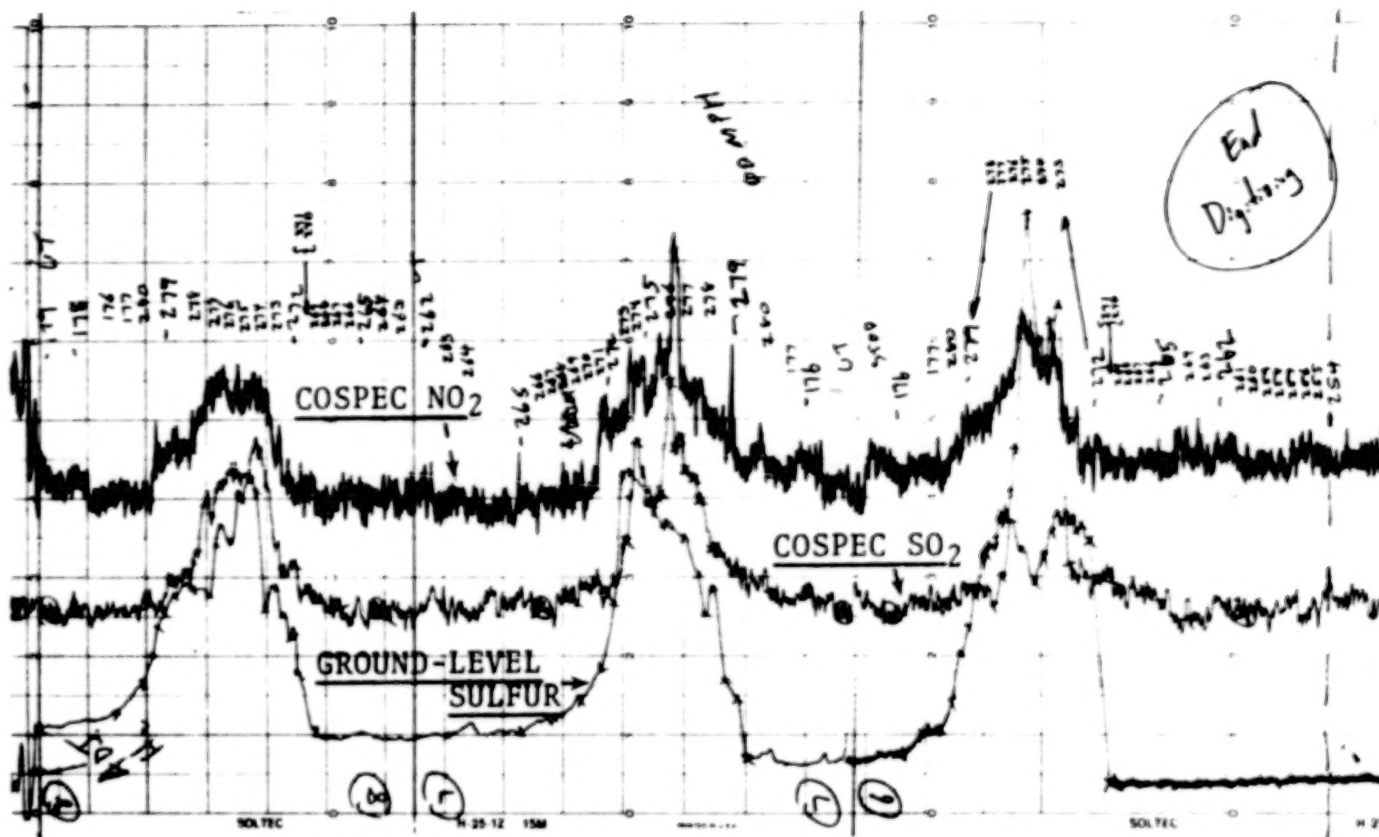
Figure 1 is a section of actual field strip-chart data showing the recorded output signals from the COSPEC and the Meloy total-sulfur monitor during three successive traverses of a power-plant plume. Geographic location information is also recorded (by hand) on the chart record. The background-to-background feature of the traversing method is apparent in each of these traverses.

### Plume-Rise Measurements

The AQML method of traversing with the COSPEC measuring in an upward-looking mode as previously described is the method most often used. COSPEC data obtained in this mode give information on the horizontal structure of the overhead SO<sub>2</sub> plume. However, information on vertical plume structure is also valuable in assessing the ground-level impact of the plume on the surrounding environment. The ground-level concentration depends on both the height of the plume center line ( $h_c$ ) and the degree to which the plume is dispersed vertically ( $\sigma_z$ ). These parameters typically appear in equations for the modeling of plume dispersion, as shown by the commonly used Gaussian plume dispersion equation for ground-level concentration:

$$C = \frac{Q}{\pi \sigma_y \sigma_z u} \exp \left[ -\frac{1}{2} \left( \frac{y}{\sigma_y} \right)^2 \right] \exp \left[ -\frac{1}{2} \left( \frac{h_c}{\sigma_z} \right)^2 \right]$$

Thus, knowing the relationships between (a) plume height and vertical width, and (b) the atmospheric parameters that determine these quantities is important in an overall program of assessing plume impact.





The COSPEC offers a straightforward method of obtaining direct measurements of plume height and width.

For measuring vertical plume structure, the COSPEC is used in a side-looking mode. It is mounted on a tripod with a calibrated panhead. The signals from the COSPEC are recorded on a chart recorder, together with interpretive notes handwritten on the chart for subsequent data processing by the person gathering the data. The COSPEC is set up at a desired distance downwind of the source, off to one side of the plume. The horizontal angle of the line of sight of the COSPEC is fixed at an angle downwind of the stack (approximately normal to the wind flow). The COSPEC is then scanned vertically through the plume with care taken to exit the plume on either side, if possible. (If the downwind distance of the scan is such that one is in the region of touchdown, it is impossible to exit the lower edge of the plume.) Several such scans (usually five to ten) are made in quick succession at the same downwind angle to compose a "set" of vertical profiles of the plume. The individual scans are made as quickly as possible to obtain a relatively short-time picture of the plume on each of these vertical scans. (The limit to the speed at which these scans can be made is the response time of the instrument (1 second) that results in 60 to 90 seconds per scan. Therefore, a set of scans requires on the order of 10 to 20 minutes.)

A series of scans must also be done upwind of the source to determine the background signal (i.e., the signal that would be present even if no sulfur dioxide were present from the source). These scans are done in exactly the same way as scans downwind of the stacks. This set is used to determine the background values that must be subtracted from the actual data scans to quantify the amount of sulfur dioxide in the line of site of the COSPEC as it is scanned vertically through the plume. The horizontal angle of the COSPEC may then be set to a new value, and the procedure for obtaining a set of scans is repeated so that data further downwind in the plume are obtained from the same measurement site.

Figure 2 is an example of the graphical output of the data processing procedure which is used to reduce the field data from a set of vertical scans. The individual scans of the set are graphed in the upper half of the plotted data. The data are further processed by averaging the scans making up a given set to provide a time-average over the period during which the set of scans was obtained. A Gaussian equivalent of this time-averaged plume is fitted by constructing a Gaussian-shaped curve whose area, mean, and standard deviation are identical to those of the time-averaged plume. The average plume curves and Gaussian equivalents are shown in the bottom halves of the plots.

The results are in terms of vertical elevation angles of the COSPEC rather than in terms of plume height and vertical spread in meters; this construction is the next step, because the complete geometry is known - if a horizontal (upward looking) traverse is conducted by a second COSPEC or before (or after) the plume rise data.

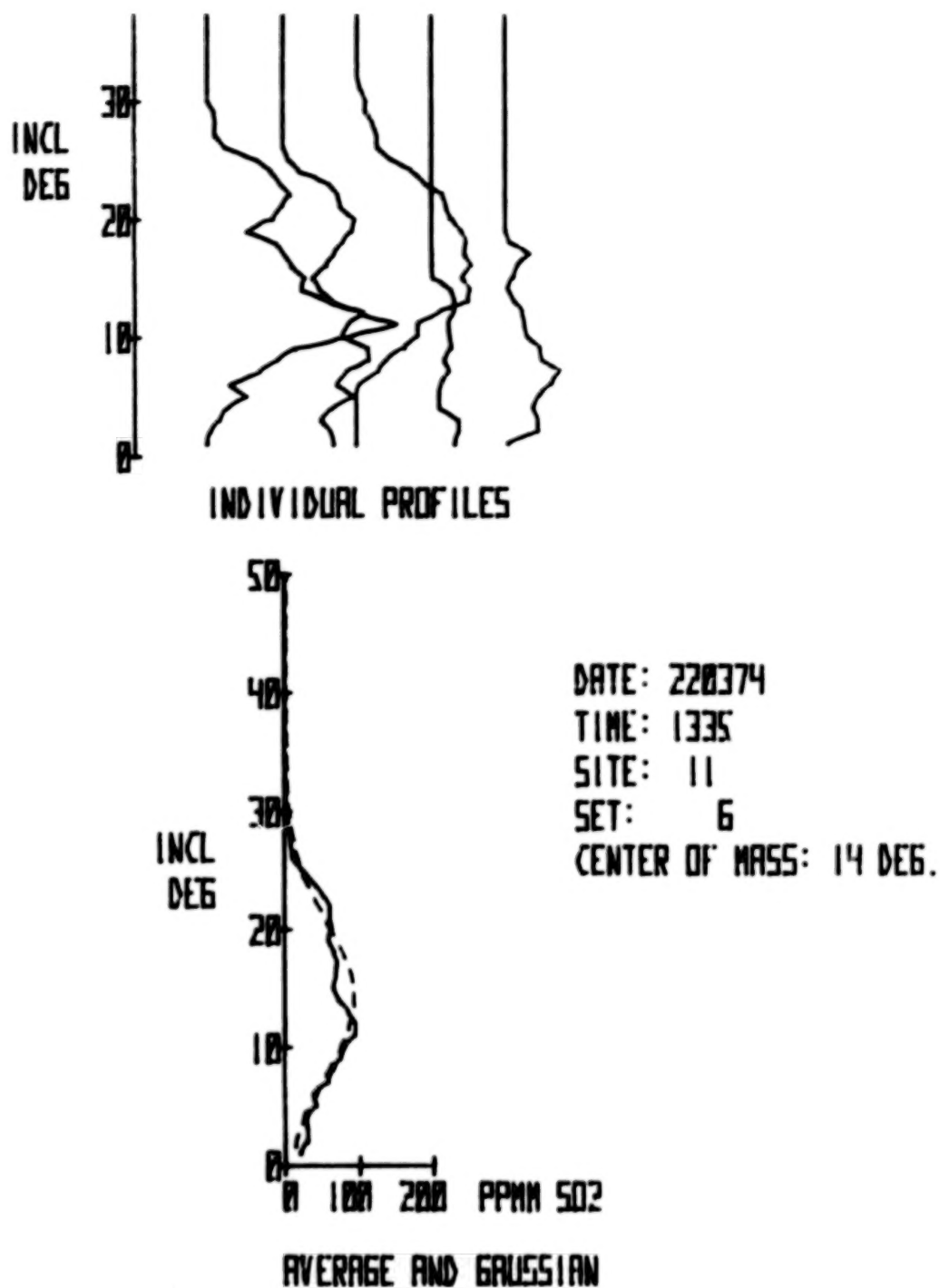


Figure 2. Sample plume-rise graphics.

## CONCLUSION

The remote sensing COSPEC has been used as an integral component of the air-quality measurement programs conducted by EMI for the Maryland Power-Plant Siting Program. Specifically, these programs have been carried out at BG&E's Wagner plant and PEPCO's plants at Chalk Point, Dickerson, and Morgantown. Data from these studies have been used for development of dispersion models and for siting studies. The COSPEC data have also been used for calculating  $\text{SO}_2$  mass-flow rates.

More recently (September to October 1976), a joint study was performed with NASA/Langley Research Center at the Morgantown power plant. In this study, NASA operated a particulate lidar to obtain complete plume cross-section data. EMI concurrently performed its standard traversing procedure, as well as plume-rise measurements from the lidar site. Data from this project are now being processed for evaluation and comparison.

More details on the measurement techniques and data processing methods are available in EMI's Annual Reports to the State. Results of the analysis of the data have been reported by Jepsen and Weil (1973) and Weil (1973).

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## LIDAR: A LASER TECHNIQUE FOR REMOTE SENSING

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### INTRODUCTION

Lasers offer increasingly practical means for remote sensing of the environment. A laser-radar (lidar) instrument transmits a short, intense, highly directional flash of light, whose backscatter or reradiation into a receiver telescope carries information about environmental conditions all along the line of sight. The variation of conditions with distance from the receiver is realized in the form of time variations in the received signal, because of the finite velocity of light ( $\sim 300 \text{ m}/\mu\text{s}$ ).

The practicality of lidar arises from the development of rugged stable lasers and electronic data systems that sort and process the time-dependent lidar returns. Lidars can be installed on ships, aircraft, and satellites, as well as on ground stations. The practical range of environmental lidar is currently about 200 m (typical for calibration) to the 200 km envisioned as the Space Shuttle altitude. Examples of various applications will be discussed here. Recent summaries of many of these topics have also been given by Melfi et al. (1977), Collis and Russell (1976), and several authors in the volume edited by Hinkley (1976).

Because of the number of proven or developing lidar concepts, their role should be routinely considered as part of the approach to a specific environmental problem such as power-plant siting. Rapid coverage of air space and water area will be characteristic advantages to be weighed against the cost and expertise required for a lidar installation. The present phase of lidar practice can be characterized as one in which significant ongoing support is needed and readily justified for field instruments and tests for better selection of the routine lidar systems of the future. Although lidar instruments will be *required* for some types of measurements, their potential will be most fully realized in conjunction with *in situ* sampling.

## REMOTE SENSING OF THE HYDROSPHERE

Experimental airborne lidar systems have proven to be useful for shallow-water bathymetric measurements (Hickman and Hogg, 1969), the detection and identification of oil slicks (Kim and Hickman, 1973), and the detection and identification of algae (Kim, 1973; and Friedman and Hickman, 1972). In addition to these proven applications, an airborne lidar system may also provide a means for measuring and tracking subsurface currents and for measuring water turbidity. All of these measurements can be taken over a wide area on a time scale far shorter than that possible with standard shipboard instrumentation by using an airborne lidar system. This has led to the development of an advanced, multipurpose lidar system denoted here as the National Aeronautics and Space Administration (NASA) Advanced Application Flight Experiment/Airborne Oceanographic Lidar (AAFE/AOL) system. This system has two modes of operation: bathymetry and fluorescence. A brief discussion of each of these subjects follows.

### Bathymetry

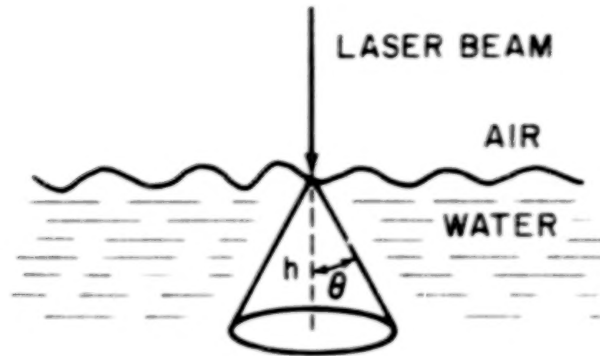
The concept of an airborne pulsed laser for bathymetry was originally proposed in the late 1960's. In 1968, G. D. Hickman (Hickman and Hogg, 1969) of Syracuse University Research Corporation demonstrated the feasibility of an airborne system. In 1971, the Naval Oceanographic Office performed similar experiments from a helicopter with a system designated as the "Pulsed-Light Airborne Depth Sounder" (PLADS) (Bright, 1973).

The utility of an airborne laser bathymetric (ALB) system for hydrographic surveys from aircraft at speeds of a few hundred kilometers per hour is of interest to various agencies that is concerned with applications involving shallow waters such as those existing in the Chesapeake Bay. One such application is that of power-plant siting, in which one is concerned with the interaction of the power plant with the shifting sediment of the inshore waters.

The severe attenuation of laser light in water dictates the use of high peak laser power, which are usually available in pulsed lasers having relatively low repetition rates. The airborne laser bathymeter is based on the principal of transmitting an intense light pulse of a few nanoseconds duration through the air/water interface. The time delay between the light pulse reflected from the water surface and that from the ocean floor is converted into a measurement of the water depth. The utility of this technique of measuring water depth depends mainly on the conditions of the water environment, such as surface roughness, water turbidity, and ocean-bottom reflectance.

During the past several years, Hickman et al. (1970 and 1972); Hickman and Ghovanlou (1973); and Ghovanlou et al. (1973) have performed extensive laboratory work on bottom sediment reflectivity and the transmission of laser light as a function of water turbidity. The measured quantity that describes the optical properties of light transmission in turbid water is the normalized, integrated power distribution,  $N_{\alpha\beta}$  ( $\alpha$ h,  $\theta$ ), where  $h$  is the water depth, and  $\alpha$  and  $\beta$

are the total attenuation and absorption coefficients of the water, respectively. This distribution expresses the total power that is contained in a cone (half-angle  $\theta$ ) at a distance,  $h$ , in water as follows:



The results of laboratory measurements were used to derive the following empirical expression for the intensity of the echo signal at the airborne receiver,  $P(\text{rec})$ , from the bottom sediment.

$P(\text{rec})$  = power incident on sediment  $\times$  attenuation of echo signal

$$= P(0) (1 - \rho) e^{-a_0 h} N_{aa}(\alpha h, \theta) \frac{R \cdot A \cdot E}{2H(H + h)^2} e^{-\Gamma \cdot h}$$

where

$N_{aa} = (\alpha h, \theta)$  = normalized power distribution

$P(0)$  = initial laser power

$\Gamma$  = effective attenuation coefficient

$= \beta (a/s)$

$\beta = 3.3$  = constant derived from experiment

$\theta$  = beam spread in water

$a_0$  = absorption coefficient of clear water

$a$  = absorption coefficient of water

$s$  = scattering coefficient of water

$A$  = area of the receiver

$E$  = optical efficiency of the receiver

$R$  = sediment reflectivity

$\rho$  = water surface reflectivity

H = altitude of airborne laser system

This equation shows that the return laser power varies as  $\exp[-\Gamma \cdot h]$  instead of the expression,  $\exp(-\alpha h)$ . The significance of these results is that the return laser power cannot be predicted solely on the basis of the value of  $\alpha$  as measured by a transmissometer *in situ*. This is because a transmissometer measures the total attenuation coefficient,  $\alpha$ , whereas  $\Gamma$  depends on the ratio of the absorption and scattering coefficients of the sediment in the water. The most recent airborne experiments of this type were made in 1974 and 1975 by Kim et al. (1975) and Kim (1977) in the area of Boca Chica Key, Florida.

The overall usefulness of the laser bathymetric method has been estimated by Lepley (1968). He concluded that, on a yearly average, 85 percent of the world's coastal water is clear enough for the use of an airborne laser fathometer for mapping sea-floor topography from the shore to at least 20 meters depth (Secchi depth  $\geq 5$  m). Such an airborne technique should permit rapid coverage of most coastal waters.

### Water Turbidity

Preliminary experiments (Hickman et al., 1973) have shown that there is a direct correlation between the amplitude and shape of the laser backscattered signal and the water turbidity. These experiments showed a linear relationship between the magnitude of the laser backscatter and the turbidity. Although this relationship was found to exist at all wavelengths, the greatest effect occurred when a wavelength excitation of 440 nm was used. These preliminary measurements indicate the feasibility of using the backscatter from an airborne laser transmitter/receiver system as a direct-reading  $\alpha$ -meter. The accuracy of this technique for measuring  $\alpha$  at 440 nm has been estimated from these results to be 5 to 10 percent. A laser operating at a still shorter wavelength (i.e., 337 nm) may yield still greater accuracy.

A second method for determining the turbidity of the water was used by Kim et al. (1975) and Kim (1977) in his recent airborne experiments. This method consists of using the measured intensities of the subsurface reflections, determined for two water depths, to yield the effective attenuation coefficient,  $\Gamma$ , of the water.

### Laser Fluorosensing Applications

A remote, active sensor system designed to detect laser-induced fluorescence from organic and biological materials in the ocean has been suggested by a number of investigators. The first prototype laser fluorosensor designed for detecting chlorophyll-*a* bearing phytoplankton was made by Kim (1973), and the initial airborne flights for detecting oil were performed by Kim and Hickman (1973). The laser fluorosensing technique is an exciting innovation that has emerged in recent years. This relatively simple technique can be engineered into surveillance aircraft and is capable of functioning as an important algae or oil surveillance system.



Both laboratory and flight tests have shown the feasibility of a laser for detecting and possibly identifying various types of oils. In general, the fluorescent spectra of oils lie between 400 and 600 nm, with maximum excitation in the ultraviolet. The pulsed nitrogen laser (337 nm) provides an excellent source of excitation for oils. Techniques are now being investigated for identifying the various types of oils by analyzing ratios of fluorescent signals at several wavelengths. The optimal wavelength for oil excitation differs from that required for either bathymetry or chlorophyll-a.

### **Dye-Fluorescence Applications**

Measurements have been made on a large number of organic dyes that exhibit absorption and fluorescence spectra in the range 480 to 600 nm (Hickman, 1973). The fluorescent intensity has been examined as a function of a number of environmental parameters (i.e., temperature, pH, salinity, and ambient light conditions).

The possibility of remotely inducing dye fluorescence by means of pulsed lasers opens up several hydrospheric applications as follows.

#### *Water Currents*

It is well known that currents can be followed by creating a dye cloud in the water and following its progress photographically and by water sampling (Betz, 1968; Foxworthy, 1965; Okubo, 1965; and Wright and Collins, 1964). Rhodamine-B and Fluorescein are the dyes usually used for tracing the motion of water. They have been used successfully in ground-water transport studies, in determining estuarine circulation, and in defining longshore currents. These dyes are inexpensive and generally stable to the influence of the various environmental conditions. Although the initial dye studies were concerned with detection of surface-released dyes, subsurface releases, including multiple color dyes, are still being investigated.

The great advantage of airborne laser mapping of a fluorescent dye is the rapidity of wide-area coverage, combined with the depth resolution that comes naturally out of the time-resolved lidar return. If, for example, the surface and bottom layers of water demonstrate a strong velocity shear, the two different flows will be automatically sensed and mapped in the lidar data reduction. In some cases of depth-variable current, one expects first to obtain a depth-averaged flow or diffusion velocity and then go to a more complicated inversion of the lidar signal to bring out the variation of dye concentration with depth.

#### *Water Temperature and Salinity*

The measurements that have been made on the effect of temperature and salinity on dye fluorescence showed a large variance among the various dyes. If a dye cloud that is composed of two different dyes is illuminated with a laser and the peak fluorescence from the dyes is independently detected, the ratio of the two fluorescent signals can be shown to be

related to the temperature of the medium. Laboratory results show that temperatures (both surface and subsurface) can be measured to  $\pm 0.5$  K with this technique. The depth from which data can be extracted depends on the water turbidity.

Similarly, the salinity coefficients vary widely among the various organic dyes. It may be possible to use a combination of dyes to obtain the salinity of the water in environments in which salinity varies widely with time and location.

Numerous applications of the airborne pulsed laser in the hydrosphere have been mentioned previously. In some cases, airborne measurements have already been made. For other applications, laboratory work is necessary before experiments are performed from an airborne platform. The important fact is that the NASA/AOL system, which was previously mentioned, is a reality. This system incorporates many desirable features, such as a mirror scanner, a laser transmitter that operates at pulse rates up to 400 pulses per second, and an onboard data processing capability. This system was designed to be of optimum use to the scientist in testing his ideas. In addition, data can be obtained that will be used in designing equipment for solving a particular problem. The application of this remote sensor to the problems of the Chesapeake Bay is limited only by the scientist's ingenuity.

### ATMOSPHERIC LIDAR

This section discusses lidar studies of the atmosphere that have either been conducted or are in an advanced stage of testing. Because lidar systems can be aimed quickly in any given direction and give range resolution along the line of sight, they can give the environmental observer unprecedented, three-dimensional pictures of atmospheric processes. Lidar imaging succeeds over distances of at least several kilometers and appears to be capable of extension to several hundred km for Space Shuttle observations of the atmosphere from Earth orbit. Of greatest interest at this conference are the efforts to date to study the local environment, most of which have been carried out from ground-based observatories or mobile vans. Several examples are discussed here of observations of aerosols and gaseous constituents; the archetype is the airborne plume from a combustion power plant, which contains: (1) effluent aerosols, (2) aerosols formed by the accretion of water onto condensation nuclei, (3) gaseous pollutants such as  $\text{SO}_2$ , and (4) naturally occurring gases such as  $\text{H}_2\text{O}$ . The capability to record time-resolved, three-dimensional pictures of these entities is central to understanding the impact of power-plant effluents on the local and downwind environment in areas such as the Chesapeake Bay region.

#### Aerosol Measurements by Lidar

Examples of general interest will be mentioned later. A study of particular interest in the Chesapeake Bay region is the recent field trial (Northam, 1977) of NASA/Langley Research Center's (LaRC's) 30-cm (12-in.) 1.5-joule ruby lidar on plume dispersion from Pepco's combustion power plant at Morgantown, Maryland. This LaRC activity was pioneered by

G. B. Northam and is conducted by Frank Mills under joint support by NASA and the Maryland Power-Plant Siting Program. The combustion plume was studied remotely at various locations up to 5 km from the source as part of an overall measurement program on how the plume rises, spreads, contorts, and settles as the effluent is blown downwind. Clearly, the downwind motion and concentration of the plume under various meteorological conditions is extremely important in assessing probable environmental impact.

The lidar is used to "see" the plume aerosols even when they are so dilute that one cannot readily spot the plume with the naked eye. The extra aerosols in the plume enhance the backscatter of laser light to the receiving telescope over and above the natural backscatter caused by other aerosols (soil, pollen, mist, etc.) and by air molecules.

Figure 1 schematically shows the lidar scanning of a plume cross section. This display can be obtained by tilting the lidar telescope through a range of elevation angles and by then intensifying the display line wherever the increased lidar return signal shows there is enhanced aerosol scattering.

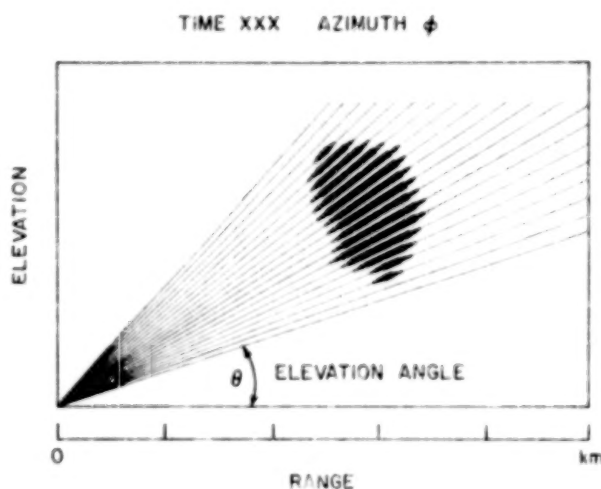


Figure 1. Example of intensity modulated plume cross-section display (courtesy of NASA/LaRC).

Quantitative intensity and coordinate data are then reduced to find the plume centroid and the horizontal and vertical dispersions ( $\sigma_y$  and  $\sigma_z$ ) about the centroid. These are parameters that appear in the Pasquill-Gifford model equation for the local aerosol concentration,  $N$ :

$$N(x, y, z; h) = \frac{kQ}{\sigma_y \sigma_z U} e^{-\frac{y^2}{2\sigma_y^2}} \left( e^{-\frac{(z-h)^2}{2\sigma_z^2}} + e^{-\frac{(z+h)^2}{2\sigma_z^2}} \right)$$

where the centroid has (vertical, horizontal) coordinates ( $z = h$ ,  $y = o$ ),  $U$  is the mean wind speed, and  $Q$  is the emission rate of the aerosol at the source.

Figure 2 illustrates the estimation of the vertical dispersion  $\sigma_z$  from computer-reduced plume cross sections obtained from the lidar data. At a given downwind location, the plume centroid was found from reduction of pictures such as in figure 1. In the vertical plane passing through the centroid, the aerosol density as a function of height was seen in this particular case to have the jagged shape shown in figure 2.

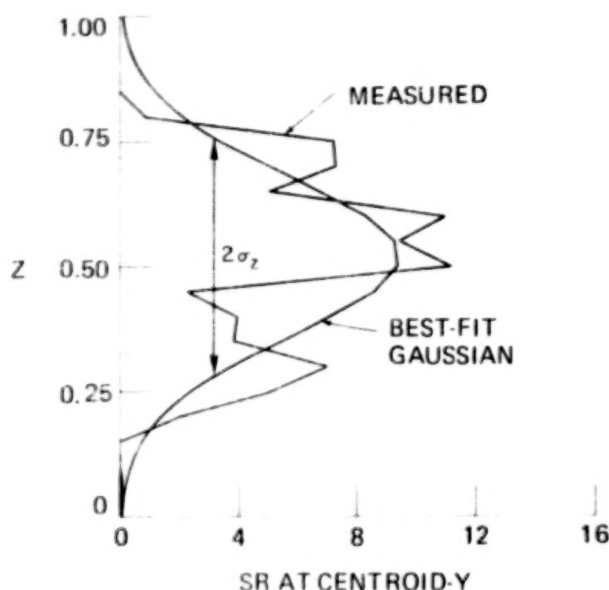


Figure 2. Lidar cross section of dispersed aerosol density in local vertical midplane of plume (courtesy of NASA/LaRC).

The average characterization of such plume parameters is necessary for summarizing plume behavior. Complete description of plumes usually requires other instruments besides lidar; in this study, for example,  $Q$  and  $U$  were obtained by other means. The great advantage afforded by lidar here is the quantitative, three-dimensional visualization of a very tenuous plume far from the immediate vicinity of the source.

Extensive studies of aerosols (Russell and Uthe, 1976) attributable to both urban air pollution and maritime haze are underway in the San Francisco Bay Area, using the Mark IX Mobile Lidar System (Uthe and Allen, 1975) built by Stanford Research Institute (SRI). SRI has many years experience in this field and is carrying out this particular study to infer the likely range of climatic changes that would be associated with enhancement of aerosol layers.

That techniques of this type are becoming more available in spite of their cost is suggestive of looming environmental problems in the interaction of man's urban/industrial effluent with the natural atmosphere. In considering regional air-pollution problems that are broader in scope than the siting of, for example, a single power plant, the environmental policy planner should bear in mind that airborne lidar systems will offer important and often unique monitoring advantages in sensitivity and rapidity of spatial coverage.

A difficulty yet to be fully overcome in the "technology transfer" of lidar developments to the environmental-user community is the largely unaccustomed set of journals in which lidar work is to be found. The following are mentioned here to illustrate the problem and to suggest where to look for new and useful work: Kent and Wright (1970); Collis (1970); McCormick and Fuller (1973); Schotland (1974); Northam et al. (1974); McCormick (1975); Grant et al. (1974); and Grant and Hake (1975).

Another lidar facility operating in the Chesapeake Bay region is NASA/LaRC's 122-cm (48-in.) system (figure 3), which has been used to study aerosols to 30 km and above, well into the stratosphere. Environmental researchers at this conference should be aware of the range capabilities of this system and of the backgrounds of the cognizant scientists, such as the work by M. P. McCormick et al. (1972) in the Willamette Valley in Oregon and Fuller et al. (1976) in which feasibility was proven for lidar measurements of aerosols and water vapor in the Earth's mixing layer.

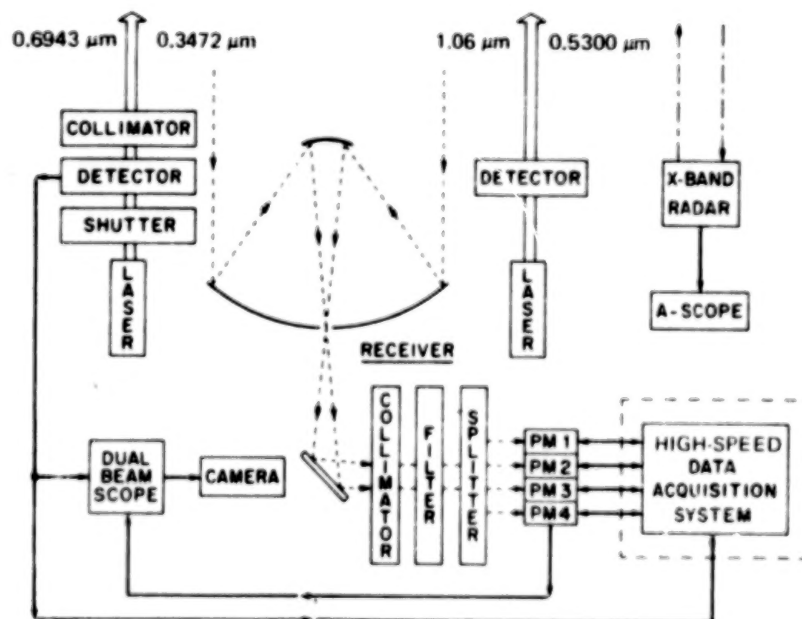


Figure 3. NASA/LaRC 122-cm (48-inch) laser radar.

The remainder of this section is concerned with capabilities for lidar measurements of gases in the atmosphere.

### Gaseous Constituents

The principal lidar technique being pursued today for measuring gases in the troposphere is differential absorption (DIAL) in which two (preferably simultaneous) laser pulses are used, one of which is tuned to an absorption line of the gas of interest (e.g.,  $\text{H}_2\text{O}$  and  $\text{SO}_2$ ), and the other is tuned off any such line. Aerosol extinction enters more or less equally into the two return signals, so that their main difference resides in the amount of the absorbing gas. One can observe the total amount of absorber between the lidar station and a distant reflector, or, if the signals attributable to aerosol backscatter are strong enough along a given atmospheric path, the distribution of absorber can be extracted from the on-line/off-line ratio of lidar returns as a function of range.

The Stanford Research Institute is the best known laboratory in this field. For example, in 1974-1975, SRI demonstrated the detection of  $\text{NO}_2$ ,  $\text{O}_3$ , and  $\text{SO}_2$  at the 300-m range, using tunable lasers in blue and ultraviolet wavelengths (Grant et al., 1974; and Grant and Hake, 1975). More recently, SRI's DIAL work has shifted to infrared wavelengths (Murray, 1976; and Murray et al., 1976a and 1976b), in which there are a number of coincidences between DF laser emission lines and the absorption lines of  $\text{HCl}$ ,  $\text{N}_2\text{O}$ , and  $\text{CH}_4$ ; results of this work follow. As a more general matter, SRI intends to exploit numerous overlaps between laser spectra and gas absorption for measuring pollution that involves  $\text{NH}_3$ ,  $\text{C}_2\text{H}_4$ ,  $\text{C}_2\text{Cl}_4$ , Freons, etc.

Figure 4 illustrates the SRI system for checking the remote detection of  $\text{HCl}$ ,  $\text{N}_2\text{O}$ , and  $\text{CH}_4$  against known amounts of these impurities in a sample chamber. Gases are cycled in and out of the chamber with the DF laser line fixed at an absorbing wavelength in each case.

Because the confined (and fairly contaminated) gases in the chamber are optically equivalent to much smaller amounts of impurities spread out over a long path, the simulation can be taken as a fairly realistic indication of the detectable ppm-km for the lidar system for each of these gases. Figure 5 shows the quality of the cross checks between optical and other monitoring, as well as sensitivity scales in ppm-km for  $\text{CH}_4$  and  $\text{N}_2\text{O}$ . It is impressive that this first system of its type comes close to being able to monitor small changes of both  $\text{CH}_4$  and  $\text{N}_2\text{O}$  relative to their natural abundances in the atmosphere. Further development of these lidar systems holds promise for important monitoring projects, including the rates at which  $\text{N}_2\text{O}$  and  $\text{CH}_4$  are produced by large-scale biological activity.

Figure 6 shows the type of laser (McIlrath et al., 1975) being used in a joint NASA/LaRC/University of Maryland experiment on atmospheric water vapor. This is another DIAL measurement, which seeks to obtain water-vapor profiles in the atmosphere by on-line/off-line operation in the very near infrared spectrum. We expect to be able to measure water vapor with satisfactory accuracy up to 2 km in height and out to comparable or greater horizontal



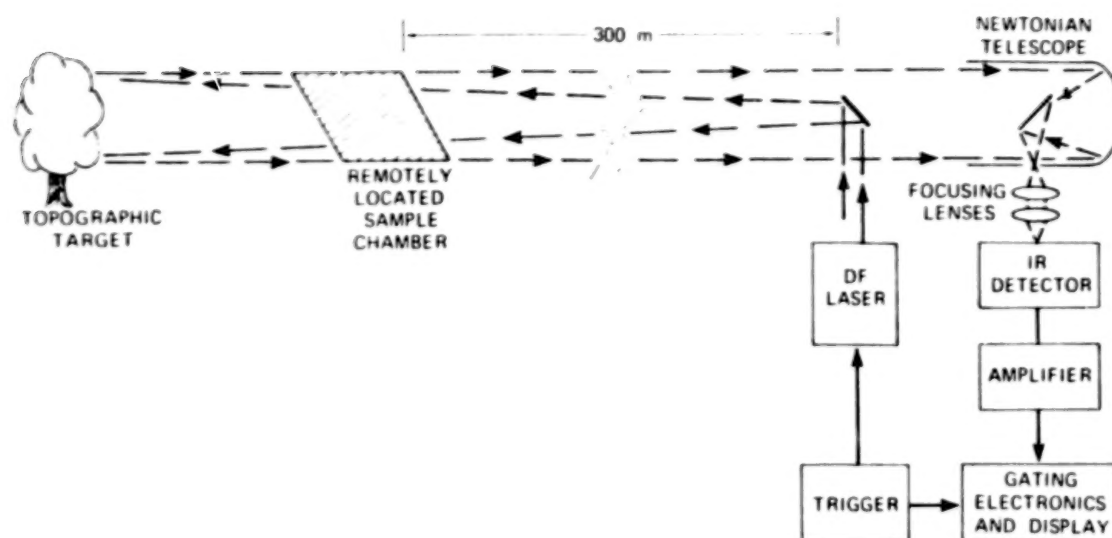


Figure 4. SRI calibration system for remote detection of  $\text{N}_2\text{O}$ ,  $\text{CH}_4$ , and  $\text{HCl}$ .

range, so as to be able to relate precipitation and fog formation more closely to the amount of  $\text{H}_2\text{O}$  present in the vapor phase. There is also a long-range interest in global  $\text{H}_2\text{O}$  profiles that might be obtainable with lasers in the Space Shuttle (Wilkerson et al., 1975).

Figure 7 shows a numerical simulation of the expected accuracy in  $[\text{H}_2\text{O}]$  in one version (Schwemmer and Wilkerson, 1976) of the LaRC/University of Maryland experiment. Although some of the rapid rise of error above a 2-km altitude is characteristic of probing the atmosphere from the densest portion (sea level) outward, most DIAL system curves display this appearance even for horizontal propagation because of extinction of the on-line (i.e., the absorbed) lidar pulse. As matters stand, we expect to obtain about five vertical range cells of good data (to  $\sim 2.3$  km) before the cumulative system errors cause serious trouble.

Figure 8 represents  $\text{H}_2\text{O}$  lidar simulation work (Schwemmer and Wilkerson, 1976) on problems of interest to the U.S. Navy, assuming high-pulse energy, a range resolution of 150 m, and a variable elevation angle for the lidar. One finds, for example, that the use of a weakly absorbing line for reaching fairly far out in the horizontal direction is a bad choice at higher elevation angles. For general purposes, the strong line (indicated) gives better lidar performance for most angles of elevation.

A point to bear in mind about simulations of this type is that they are extremely useful fore-runners of any proposed measurement program. At the University of Maryland, SRI, and NASA/LaRC, such simulations are routinely used to improve the definition of experiments and to check the consequences of all pertinent data. One of the goals of the current LaRC/University of Maryland work is to compare the observed measurement errors with those simulated ahead of time.

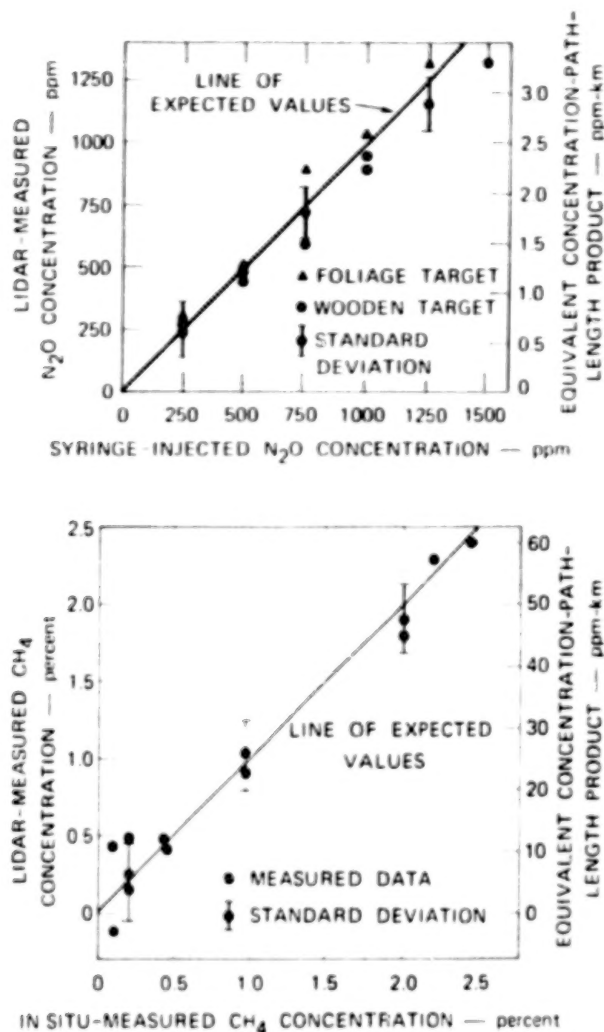


Figure 5. Calibration of SRI lidar sensitivity for N<sub>2</sub>O (upper) and CH<sub>4</sub> (lower) against target samples. Right-hand scale indicates ppm equivalents for 1 km path-length (Murray et al., 1976a and 1976b).

The comparison should prove useful in the general field of DIAL measurements of atmospheric gases. This field is proving to be fairly challenging and harder to develop than the aerosol work because of the much greater spectral definition required. Nonetheless, an appreciable number of natural and pollutant gases has now been measured remotely by lidar methods, and the way seems clear towards greater accuracy and more species.



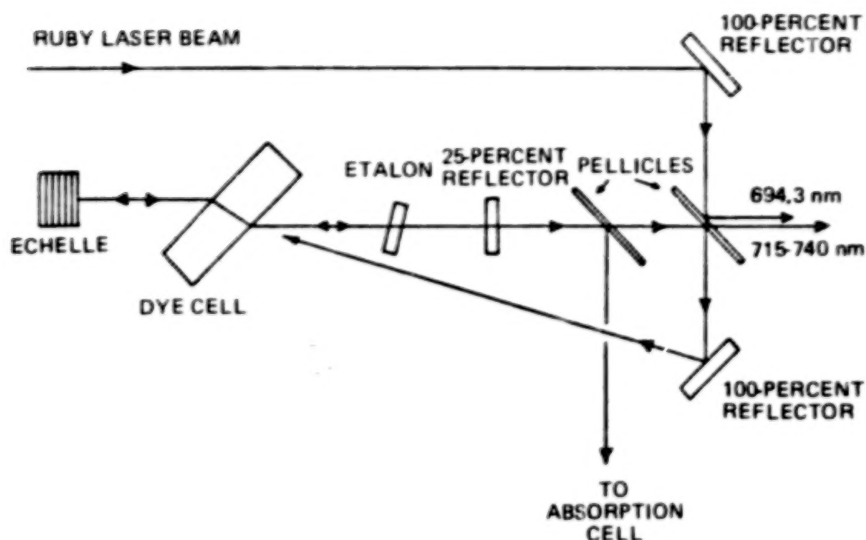


Figure 6. Tunable dye laser for  $\text{H}_2\text{O}$  (University of Maryland) pumped by ruby laser (NASA/LaRC) (McIlrath et al., 1975).

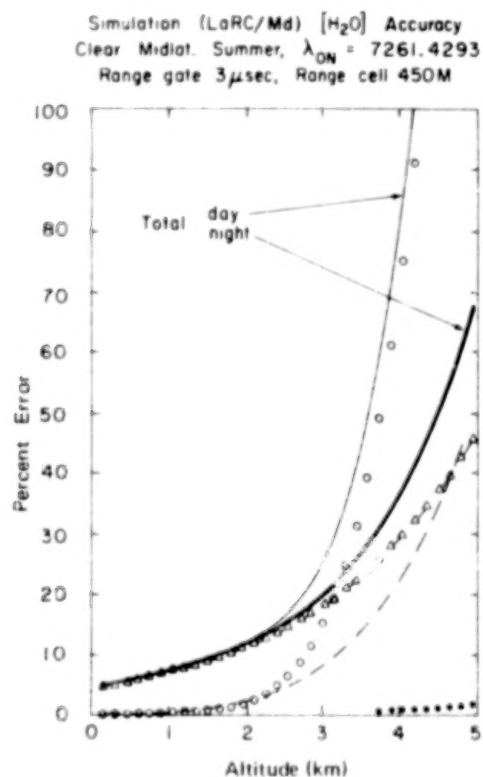


Figure 7. Overall accuracy prediction for an  $\text{H}_2\text{O}$  experiment as a function of vertical range (Schwemmer and Wilkerson, 1976).

H<sub>2</sub>O Lidar: Ten-percent accuracy contours for (H<sub>2</sub>O)  
clear, midlatitude summer conditions  
weak versus strong (\*) H<sub>2</sub>O lines

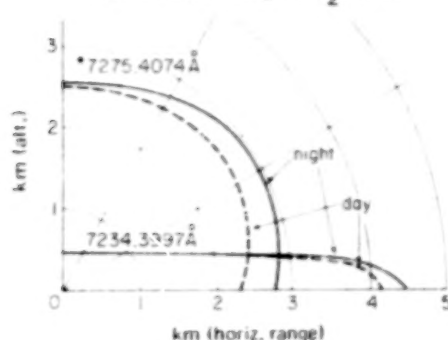


Figure 8. Error dependence on slant range  
for H<sub>2</sub>O lidar using weak and strong H<sub>2</sub>O lines.

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## WATER QUALITY AND SHELLFISH SANITATION

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The Environmental Health Administration of the Maryland Department of Health and Mental Hygiene regulates the public health aspects of shellfish harvesting. This responsibility emanates from a cooperative control procedure entitled the "National Shellfish Sanitation Program" (NSSP) and is administered by the United States Food and Drug Administration.

The NSSP requires that all shellfish-producing waters be classified as to their acceptability by meeting certain minimum standards. To classify these areas, sanitary surveys are conducted. These surveys must include an evaluation of actual or potential pollution on the estuary and its tributaries and the distance of such sources from the growing areas—effectiveness and reliability of sewage-treatment plants; the presence of industrial and agricultural wastes, pesticides, heavy metals, or radionuclides that would cause a public health hazard to the consumer of the shellfish; and the effect of wind, stream flow, and tidal currents in distributing polluting materials over the growing areas.

The present monitoring program entails the monthly collection of bacteriological water samples and the determination of physical parameters at approximately 2200 stations located in the Bay and its tributaries. Shellstock is routinely collected for bacterial and chemical analysis from the various growing areas. Survey crews conduct a property-by-property evaluation in all land areas adjacent to growing waters to identify and eliminate sources of pollution. There is also an ongoing sampling program of effluents from sewage treatment facilities.

Remote sensing techniques have previously been used on a limited basis in the program. For approximately 1 year (1973-1974) in a joint project with the Goddard Space Flight Center, ERTS-1 (Earth Resources Technology Satellite) multispectral data from the Patuxent and Choptank River watersheds were analyzed in an attempt to differentiate water-feature pixels from other Earth-surface features. Water samples were collected to coincide with these overflights to establish signature values corresponding to different levels of organic matter. An attempt was then made to correlate bacteriological data with ERTS information to identify pollutional sources. Success was limited because the "pixel" represented an average area of approximately 4 km<sup>2</sup> (1 acre), which was often not fine enough to be productive for these purposes.

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During storm Eloise in September of 1975, overflights of the Bay and its major tributaries were made by the Environmental Health Administration personnel to evaluate the extent of the impact of this storm. In contrast to the limited success previously mentioned, the information developed from these overflights was invaluable in making a true assessment of this situation. Decisions to close shellfish-harvesting waters for public-health reasons were made directly from this information. Weather conditions made it impossible to obtain samples for analysis, and the situation was so serious that immediate decisions had to be made on the basis of the best information available at that time. Without the overflight information, truly rational decisions could not have been made in terms of what areas should or should not be closed for harvesting. In this instance, remote sensing played a dramatic part in the overall decision-making process.

The use of remote sensing techniques for collecting bacteriological, physical, and chemical water-quality data, locating point and nonpoint sources of pollution, and developing hydrological data could be extremely valuable to this program if they could produce the foregoing information effectively and rapidly with a minimum amount of ground corroboration.

## EUTROPHICATION IN THE CHESAPEAKE BAY

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The most critical long-term threat to the continued health of the Chesapeake Bay is the addition of excess nutrients to the estuarine waters. Other problems, such as Kepone and the disappearance of aquatic vegetation (which is possibly linked with nutrient loading), may steal our attention for short periods, but these difficulties will, hopefully, recede in due time. The projected growth of population in the near environs of the Bay, however, indicates that, as a problem, eutrophication will probably continue well into the next century.

The etymological roots for eutrophication refer to food and health. Indeed, estuaries are such bountiful waters precisely because the input of natural chemical nutrients is high compared to that of oceanic waters. Unfortunately, the utility of estuaries (or any aquatic system) does not continue to increase with greater nutrient input. Nor does the problem lie completely with the associated pathogens about which Dr. Eisenberg spoke. Rather, there comes a point at which the primary plant growth stimulated by high nutrient values creates respiratory and decompositional oxygen demand that drives the available oxygen levels to catastrophically low values ( $<4$  ppm), thereby threatening or killing the higher trophic level species. The resultant simplified system of primary producers and decomposers usually has little economic, recreational, or esthetic value.

In an earlier survey commissioned by the National Aeronautics and Space Administration (NASA) (Ulanowicz, 1974), the author catalogued the various sources of nutrients into the Bay and some areas in which these sources are causing difficulty. Perhaps a review of the effluent types would be pertinent to this discussion.

Certainly, the most acute eutrophication problems in the Bay arise in proximity to municipal sewage-treatment plants. Although these facilities remove 60 to 80 percent of the carbonaceous oxygen demand, most of the nitrogen and phosphorous in the stream passes into the receiving waters to act as fertilizer. Each of the four major metropolitan districts have associated tributaries of the Bay in which bloom conditions prevail and oxygen deficiencies are frequent. Baltimore's sewage is the major cause of anaerobic conditions in the Back River estuary and is a major contributing factor to dissolved-oxygen sags in the Patapsco estuary. The Potomac Estuary is often covered during the summer with mats of blue-green algae for 55 kilometers downstream of Washington. The upper James Estuary frequently receives pulses of raw sewage when flooding occurs, and the Environmental Protection Agency has found agglomerated fecal material in some of the water samples taken in the Portsmouth/Little Creek area (Lear, private communication, 1972).

Water draining agricultural lands can carry with it significant amounts of fertilizer and animal waste. The Sassafras, Elk, and Northeast Rivers sometimes host blue-green algae blooms believed to be the result of fertilizer runoff. Drainage from swine operations along the tributaries of the Potomac and James River Estuaries have caused problems in these embayments.

Septic-tank disposal of domestic sewage is not always totally effective, especially where poor percolation exists because of hardpan soils or high groundwater tables. To date, most difficulties center around the bacterial load from such seepage rather than the associated nutrient load. Affected shorelines include Baltimore and Anne Arundel counties in Maryland and York County in Virginia.

Human waste from recreational and commercial vessels is probably an inconsequential nutrient addition to open waters; however, overboard disposal in small embayments with many marinas or heavy boat traffic may be another matter, even though the law prohibits such disposal while in dock. A preliminary survey in the South River (Dinsdale, 1975) indicates that vessel discharges pale in comparison to the input from natural runoff. The frequency of blooms in other harbor areas, such as Annapolis, Solomons, St. Michaels, Delta-ville, Reedville, Yorktown, and Newport News, suggests that input rates and tidal flushing characteristics may make these harbors more susceptible to eutrophication from sewage discharge from boats.

Finally, the remaining nutrient input to the Bay can be lumped into a single category—nonpoint source additions. It is evident from natural history that runoff from most natural areas can be adequately handled by the estuarine cycles. But runoff from suburban and metropolitan areas is often of another order of magnitude. It has been estimated that the total runoff from the urban section of the watershed adds more nutrients to the system than the sewage plant discharges.

From the foregoing, one might deduce that eutrophication is a localized phenomenon in Chesapeake Bay and that the larger mass of water supported a reasonably healthy ecosystem. Until a few years ago, this was a widely held opinion by most of the scientific and management community. Unfortunately, there are signs that the Bay as a whole may be becoming vulnerable to excessive nutrients. Figure 1 illustrates a trend observed in the lower Patuxent Estuary that may indicate the future of the main stem of the Bay. The freshwater region of the Patuxent has been progressively burdened with sewage loading from the Prince George's and Anne Arundel suburban areas. Through the early 1960's, the chlorophyll levels in the lower estuary remained at a normal level for a healthy estuary. With loadings approaching 90 million liters/day in later years, however, chlorophyll levels associated with bloom conditions ( $40 \mu\text{g/l}$  chlorophyll) are being consistently observed.

Likewise, patches of phytoplankton blooms were occasional events in the open Bay during the late summer and early fall months. Although data on such transient events is hard to

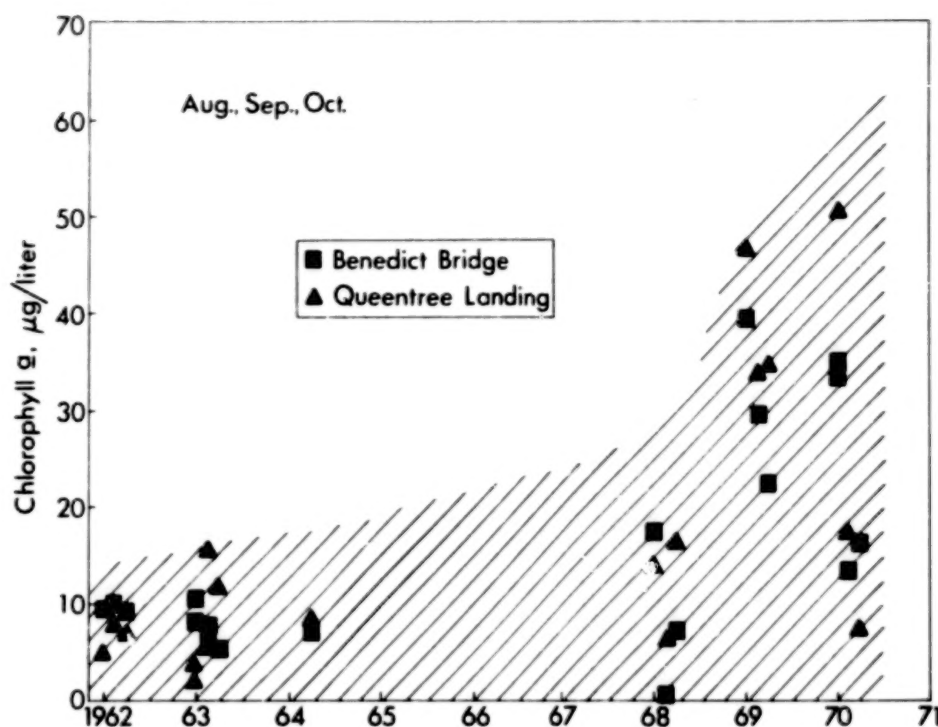


Figure 1. Lower Patuxent Estuary, August through October (Heinle, unpublished data, 1977).

assemble, there are probably few scientists on the Bay who would argue with the author's observation that such blooms are becoming more frequent (to the point of becoming sustained) and are occurring over a longer portion of the year.

Given the magnitude of the problem and the portents of things to come, one might draw some comfort from knowing that the scientific, managerial, and political communities were unanimous in opinion as to what must be done to halt and reverse the nutrient trend. Alas, there are strong differences of opinion on how best to alleviate the difficulties.

One issue revolves around land-versus-water disposal of wastes (and associated nutrients). An attractive alternative to burdening the waterways and estuaries with sewage effluent is the application of wastewater onto the land, where nutrients, and water, rather than oxygen, tend to limit ecosystem productivity. There is question, however, as to whether the public will accept land disposal as a hygienic alternative. There is even further controversy over the relative economics of land-versus-water disposal, because the major capital outlay necessary for acquisition of land to receive the wastes is great. Furthermore, possible problems with the land system remain that, in the eyes of some, have not been adequately investigated. These include heavy metal accumulation, runoff from the disposal area, leaching into ground-water supplies, etc.



In any event, it is unlikely that all sewage generated in the Bay area will be returned to the land in the near future. The question remains as to how to most effectively "retrofit" existing plants to prevent excessive nutrient stimulation in the estuary. The practical choice is between the removal of phosphorous versus the removal of nitrogen. Phosphorous is by far the easier element to eliminate from the effluent, and its removal can significantly inhibit blooms in naturally phosphorous-limited ecosystems, such as those often found in freshwater. However, some investigators are convinced that nitrogen (which is very costly to remove) is the limiting nutrient in estuarine systems and that phosphorous removal alone would be quite ineffective (Heinle, private communication, 1976). Indeed the nitrogen-limitation theory would neatly explain how sewage input from upstream is stimulating productivity in the lower estuaries, because the uptake of some nitrogen species (notably  $\text{NO}_3$  and  $\text{NO}_2$ ) is slow enough to permit significant transport of these nutrients downstream.

A strategy for nutrient control will cost hundreds of millions of dollars, and the wrong choice could waste most of the effort. The pressure is on the managers to make a decision soon. A stronger case for good data could not be made.

Remote sensing can be a vital tool for the acquisition of fast, reliable data on the nutrient problem. Synoptic data from large spatial domains are difficult to obtain from other methodologies. However, I would like to mention some shortcomings of remote sensing data.

The reader may have gathered from the foregoing that the primary interest of many investigators is on the nutrient concentrations. Chemically, these nutrients are present in dilute concentrations, usually measured in milligram (or sometimes microgram) atoms per liter. Therefore, with the remote sensing technologies in use we cannot directly measure the nutrient concentrations, but must be satisfied with observing the effects of the nutrients (e.g., chlorophyll) or with following a variable associated with nutrient input streams (e.g., sediment or temperature).

Therefore, a premium exists on the development of any remote sensing technology that would directly sense nutrient concentrations. I know of no techniques under development for the actual remote sensing of nutrient species. However, there is interest in developing *in-situ* techniques such as ion-specific electrodes (Cadman, private communication, 1973) and laser Raman spectroscopy (Freer, private communication, 1973) that could be telemetered to a central location. Although not remote sensing in the pure sense, such techniques would nevertheless obviate the need for wet analysis of all samples and would provide synoptic measurements over a wide area at a variety of depths.

A second major limitation to remote sensing techniques is their relative inability to monitor subsurface events. The Bay, a partially stratified estuary, often first exhibits eutrophic conditions at depth.



These shortcomings are mentioned primarily to give the biological investigator's priorities for defining potential research on the extension of remote sensing capabilities as they relate to research on eutrophication.

Certainly, the foregoing is not meant to minimize the important contributions that remote sensing can make by gathering information on the effects of nutrient loading. Especially useful are the chlorophyll concentration maps that can be derived by multispectral scans or lidar techniques. The possibility of mapping phytoplankton patches according to genera by using multiple wavelength lidar techniques is exciting and extremely labor-saving.

Also of immense value are the old war-horses—black-and-white, color, and color infrared photography. Their use in assessing runoff spotting seepage from holding ponds and septic systems, censusing vessels to estimate discharge, and evaluating vegetational and soil structure changes associated with land disposal has significantly aided those charged with setting and enforcing effluent standards.

There remain, however, some basic issues to be resolved if an optimal solution of the nutrient problem is to be effected. The extension of available technologies would enable the remote sensing community to make an invaluable contribution to charting this key strategy for maintaining the health and utility of the Chesapeake Bay.

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## INFERRING NUTRIENT LOADING OF ESTUARINE SYSTEMS BY REMOTE SENSING OF AQUATIC VEGETATION

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### INTRODUCTION

Nutrient loading and sediment present water-quality problems in many estuarine systems, including the Chesapeake Bay and its tributaries. Several investigators have used remote sensing, including aerial photography and thermal imagery, to qualitatively examine estuarine systems for water-quality problems. Recent research has centered around the use of remote sensing to quantitatively estimate sediment and chlorophyll content of estuaries.

Major point sources of pollutants are known, and control measures have been instituted in some areas of the Bay. However, nonpoint sources (NPS) are also considered to be a major factor in Bay pollution. These are considerably more difficult to locate and control than point sources. Remote sensing appears to have great potential for identifying nonpoint sources of nutrients and sediments.

Experiments involving the use of remote sensing for inferring nutrient loading have been approached from two standpoints:

- Identification of nutrient loading sites through field investigation or low-altitude photography of sentinel aquatic plants; use of available high-altitude photography to identify land use for the drainage basin; map potential nonpoint sources of nutrients; selective water sampling to quantify results; recommend best management practices.
- Use of Landsat or high-altitude photography to develop land-use data base; infer potential NPS from land-use and corollary data such as topography, these inferences being derived from visual interpretation or by fitting to an NPS model; low-altitude aircraft surveillance for vegetative indicators of nutrient loading; selective water sampling to quantify results; best management practices.

Examples of both of these approaches will be presented.

## VEGETATIVE INDICATORS OF NUTRIENT LOADING IN THE CHESAPEAKE BAY

### Algae

Three genera of blue-green and two genera of green algae appear to be the most common algal indicators of nutrient loading in Chesapeake Bay. These are:

- Blue-green algae
  - Anacoptis cyanea
  - Anabaena sp.
  - Oscillatoria sp.
- Green algae
  - Cladophora sp.
  - Ulva lactuca
  - Chlorella sp.

The blue-greens are most commonly found as surface blankets on water or mud flats when severe blooms occur. The greens are commonly attached to objects or washed up along shorelines.

### Vascular Aquatics

The Bay contains at least 12 common, rooted, vascular plants. Each has a potential for becoming a nuisance when nutrient levels accelerate. High turbidity levels tend to limit distribution however, even when nutrient levels are high. The following have been identified as the most probable to be encountered:

- *Myriophyllum spicatum*
- *Ceratophyllum demersum*
- *Potamogeton perfoliatus*
- *Elodea canadensis*

However, distribution and population fluxes of vascular aquatics in the Bay are poorly understood. Although some studies are now being conducted to better know these phenomena, consistent data collection over an extended period of time is needed.

## REMOTE SENSING OF VEGETATIVE INDICATORS OF NUTRIENT LOADING

### Algae

Remote analysis of algae has been approached from two standpoints:

- Qualitative estimation of algal concentration using color infrared photography
- Quantitative estimate of chlorophyll in surface water using multispectral scanners

#### *Qualitative analysis*

Several investigators (Anderson et al., 1974; Scherz, 1971; and Bressette, 1973) have shown the usefulness of aerial photography, particularly color infrared, for observing serious algal infestations in lakes and rivers.

#### *Quantitative analysis*

A considerable amount of work has been done to provide accurate, remotely sensed, quantitative measurements of chlorophyll in estuarine waters. Initial efforts such as those of Gramms and Boyle (1971) involved measurements of reflectance and transmittance of green and blue-green algae. These data were to be used in selecting narrowband channels in multispectral scanners.

Arveson et al. (1971) and, more recently, Johnson (1977) have attempted to quantitatively estimate chlorophyll with remotely sensed data. The most recent work by Johnson used an aircraft-mounted modulated multispectral scanner and an ocean color scanner calibrated with sea truth to measure chlorophyll *a* in the James River and New York Bight. Maps of chlorophyll concentration were produced for each area.

### Vascular Aquatics

Because most vascular aquatic plants remain wholly submerged, it has been difficult to develop techniques for separating species by remote sensing. It is possible to use color or color infrared photography to image the extent of aquatic plant beds in relatively shallow waters. Davis and Brinson (1976) developed a technique for estimating biomass of submerged aquatics in the Pimlico River. Anderson (1972) reviewed high-altitude photography of the Chesapeake Bay and estimated general distribution patterns of vascular aquatics.

## RELATIONSHIP OF VEGETATIVE INDICATORS OF NUTRIENT LOADING AND SOURCES OF NUTRIENTS

Little is gained by simply identifying that a nutrient problem exists by indicator vegetation or any other means if the task stops at that point. The next step of identifying sources and instituting control measures is an extremely important and difficult one. Point sources of nutrient loading have been identified in the Chesapeake Bay region. Control measures are

being instituted to alleviate the problems. More difficult source identification problems are those that are classified as NPS.

This paper proposes that remote sensing could be utilized in different ways to identify NPS areas and to provide data for NPS models. Figure 1 summarizes a multilevel approach to using remote sensing with correlative ground data for NPS identification. Two studies have been conducted that illustrate the potential for use of remote sensing:

- Anderson et al. (1974) conducted a study of sediment and nutrient sources in the Northeast River, Upper Chesapeake Bay. National Aeronautics and Space Administration (NASA) U-2 photography showed sediment and algal blooms at the mouth of the Northeast River. The study was conducted to determine if the photography could be used to identify sources of these pollution problems. Sediment and algal blooms were traced into separate tributaries of the Northeast River. Sediment sources were determined to be runoff from unvegetated agricultural fields and also from gravel washing operations. Algal blooms were traced to a small tributary with a sewage overflow problem.

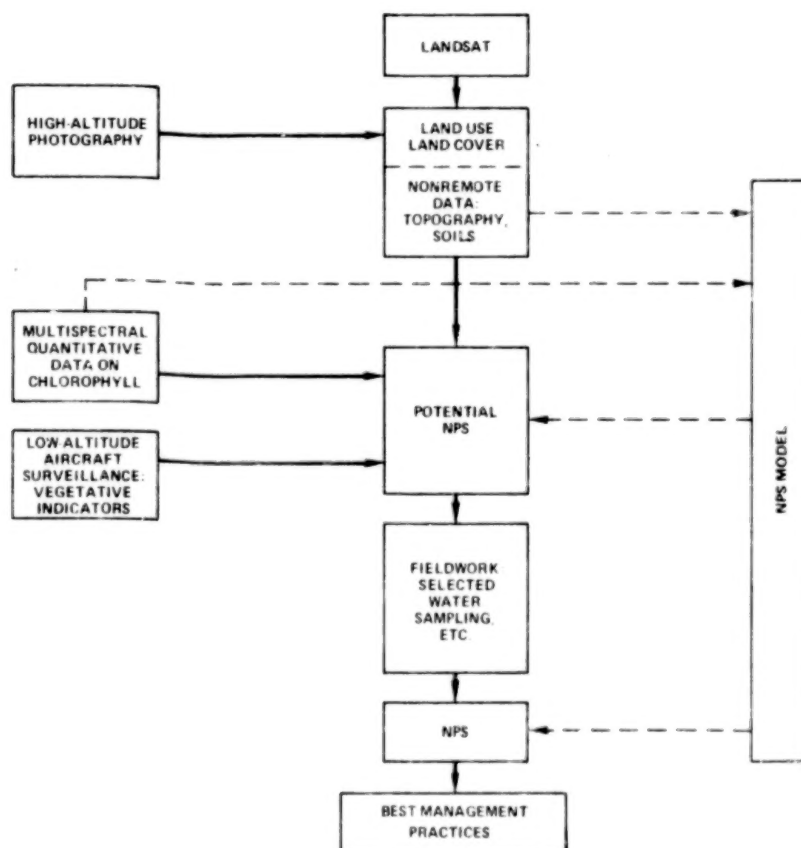


Figure 1. Summary of multilevel approaches.

- Macomber (1976) has used a combination of NASA U-2 and low-altitude aircraft photography to trace vegetative indicators of pollution to potential NPS in the Monacacy River, Maryland. He was able to qualitatively separate small tributaries according to nutrient content on the basis of vegetation and thus establish potential agricultural sources of nutrients.

Multilevel approaches to combining remote sensing data with vegetative indicator species provide nutrient source information. Although these techniques are limited to NPS in rural areas, they may be expanded to urban areas. Figure 1 summarizes the approach, which is basically as follows:

- Photo-basemaps are produced from Landsat at a scale of 1:250,000. Land cover and land use are interpreted from the Landsat imagery and are recorded as overlays to basemaps. The following physiographic data are derived from existing data and are displayed as overlays to the Landsat photo-basemap: topography, tributary network, soils and soil erodibility classes, rainfall, and watershed subbasins. When combined with land cover and use information, the physiographic data provides a method for hierarchically classifying watershed subbasins on the basis of potential nutrient sources.
- The second phase is to use watershed subbasin information generated in the initial phase to direct more detailed watershed analysis. When available, high-altitude (NASA and U-2) photography may be used to generate photo-basemaps to a 1:24,000 scale or larger. A more detailed subbasin assessment may be made by combining land use and cover interpreted from the photography with physiographic information previously listed. Based on these data elements, subbasins contributing NPS nutrients may be identified.
- The third phase involves use of selected low-altitude photography and/or multispectral quantitative analysis of chlorophyll to detect vegetative indicators of nutrient sources. The sites for this phase may be intelligently selected as a result of data analysis in previous phases. Tributaries as small as ditches may be detected with the low-altitude photography and may be evaluated with regard to potential nutrient sources by the presence of aquatic vegetation.
- The fourth phase involves selected ground work, including water sampling to acquire quantitative nutrient information where none exists. Ground sampling may be efficiently planned.

## CONCLUSIONS

Ample evidence supports the use of remote sensing to record algal and vascular aquatic plant growths in estuarine waters. It is not possible in most cases to separate species. Excessive growths of some aquatic plants may be related to nutrient pollution. A remote sensing

technique has been proposed that uses a combination of data to hierarchically classify watersheds with regard to severity of potential pollution. Lower altitude photography of vegetation and selected ground sampling may be used to identify specific NPS of nutrients in tributaries of the watershed.

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**SESSIONS 5 AND 6**

**WORKING GROUPS, OPEN SESSIONS,  
SUMMARY REPORTS, AND CONCLUDING  
REFLECTIONS**

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## INTRODUCTION\*

**Murray Felsher**

*NASA Headquarters  
Washington, D.C.*

and

**Norman H. MacLeod**

*Earth Resources Development Research Institute  
Washington, D.C.*

Conference goals included an exchange of ideas on concerns of interest to all participants, both to ensure that such concerns were addressed and to add knowledge from the expertise of participants to knowledge obtained from speakers and panelists. The concerns of participants were determined from responses to question 8 of a questionnaire sent and returned before the Conference: What are your hopes for the Conference for you and your work with respect to remote sensing? List three. Over 100 discrete concerns were identified. (A list is available upon request.) These concerns were grouped into eight categories as follows:

- Contribution of remote sensing to understanding the Bay as a system
- Role of remote sensing in documenting living resources
- Role of remote sensing in facility siting
- Role of remote sensing in documenting land use as it affects the Bay measurements (including data management)
- Role of remote sensing in Bay measurements (including data management)
- Public awareness, institutional arrangements, and funding possibilities related to remote sensing in the Chesapeake Bay region
- Role of remote sensing in physical representations of the Bay
- Role of remote sensing in documenting episodic events

Each category was to be discussed and reported on by a work group at the conference. Murray Felsher, NASA Headquarters, served as coordinator. Chairpersons were selected for each work group, and participants were asked to sign up for one of these work groups.

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\*Authored by Dixie A. Pemberton.

Because no one registered for categories 7 or 8, work groups were formed for the first six categories only.

The same problem-solving sequence of six steps developed by Leonard M. Lansky was used in each work group. His model, based on Lewin's force-field theory, was distributed as a worksheet that directed conferees to:

- Determine the present situation with as complete a listing of details as possible
- Identify the forces for and against changes, including legal and emotional factors
- Describe what the new situation should be like in positive terms, being as realistic as possible
- List alternatives for action by including each and every idea
- Assess the alternatives by weighing advantages and disadvantages, eliminating the alternatives that would not achieve the objective one wants, but not the alternatives that appear risky or impractical at first glance
- Sequence the action ideas to implement acceptable alternatives in three stages:
  - Stage 1—What happens first, second, etc? Who is needed to do what at what stages? How long will each step take? What side effects should be planned for?
  - Stage 2—Exactly who on your team will do what, when? Who coordinates? What is mutual accountability? What are sanctions (supports) for action or delays?
  - Check—Is the blueprint clear (Step 3) so that you will know when a step is completed and done as you wish? Is everyone clear about who is to do what, when, and when you will meet next?

This sequence was designed both to aid participants in relating to each other in work groups and to ensure more uniform response in reporting on work-group activities.

Work groups functioned on their own, meeting from after lunch on Thursday, April 12, through noon the following day, as each work group decided. This flexible schedule permitted work-group participants to attend any of the six open sessions held during the same period. These informal but important responses to a pre-Conference request included (in order presented at Conference):

- Harold M. Cassell, Maryland Water Resources Administration, "An Application of Remote Sensing to Mapping Tidal Wetlands in Maryland"
- John C. McFall, NASA/Langley Research Center, "Remote Sensing of Salinity"

- Carl D. Orio, Environmental Research and Technology, Inc. and Vaughn Corporation, "Regionalized Water-Quality Monitoring Systems"
- John C. Stewart, Maryland-National Capital Parks and Planning Commission, "Computer Mapping in Montgomery County"
- John C. Munday, Virginia Institute of Marine Science, "Progress Toward a Circulation Atlas"
- Philip J. Cressy, NASA/Goddard Space Flight Center; James E. Manley, Regional Planning Council; Dolly Helfer, Computer Sciences Corporation; "Hands on Demonstration of Penn State Office of Remote Sensing and Environmental Research (ORSER) System Using Telephone Hookup for Responding to Individual Inquiries"

During Session 6, each work group reported its findings to Conference participants as a whole, and answered the questions of other participants. Chairpersons remained a day after the Conference to incorporate this feedback on the working papers into the following final work-group reports. These reports omit how steps 1 through 4 of Lansky's problem-solving sequence were handled because of subsequent editorial decisions. Each report includes several post-Conference additions and revisions focused on completing steps 5 and 6.

Dr. Norman H. MacLeod gave a Conference summary at the end of Session 6. His remarks were based on a challenge to him to observe, listen, and feel what went on at the Conference from beginning to end.

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## **CONTRIBUTION OF REMOTE SENSING TO UNDERSTANDING THE BAY AS A SYSTEM**

**Archibald B. Fark, Chairperson**

**Daniel Anderson**

**Charles G. Bohn**

**Wayne Chen**

**Robert W. Johnson**

### **INTRODUCTION**

In considering a target as large and dynamic as the Chesapeake Bay, remote sensing from satellites possesses two indispensable attributes: (1) the synoptic view that one can achieve from space (e.g., 185-km swath from Landsats to 2800-km swath from Metsats), and (2) the repetitive observations that are uniquely affordable from space (e.g., 18-day repeat cycle of Landsat (9 days from Landsat-1 and -2 or 6 and 12 days from Landsat-1 and -2) to day/night observations from Metsats (full observations for a 24-hour day with DAPP)).

Remote sensing from aircraft can provide much more detail than from satellites (e.g., Landsat-1 and -2 furnishes 80-m resolution, whereas aircraft supply less than one meter). There is no regularly scheduled acquisition system for providing repetitive coverage for dynamic processes, and, even if there were, it is questionable if any agency could afford such a system. Metsats currently provide approximately 8/10-km resolution in the visible and ranges of 8/10 to 2-km in the thermal infrared for polar orbiters. Geosynchronous Metsats (Geostationary Operational Environmental Satellite) offer coarser spatial resolution (2 to 8 km) but much finer temporal resolution (30 minutes full-frame, -7.5 minutes zoom). It follows that the perspective of the problem is either very large, very dynamic, or both. Because these two attributes describe the Chesapeake Bay, it is appropriate to determine what this new technology can contribute to understanding the Bay.

Before one can proceed directly to address these issues, two questions must be asked: (1) What is the Chesapeake Bay—just the brackish water in the estuary proper? Does one include the tributaries? How far up the tributaries? What about the land? What about the air? (2) What is meant by the term “system”—the physical system, the biological or chemical systems, or all of these? Because neither answer is self-evident, the panel made the following assumptions.

- The Chesapeake Bay is assumed to include the lithosphere, the hydrosphere, the atmosphere, and the biosphere (that is, the verticle profile encompassed by the



systems and a two-dimensional plane defining the total watershed of the Bay from the headwaters of its tributaries to a distance in the ocean defined by ten tidal cycles.

- The Chesapeake Bay system is assumed to be the ecosystem in the largest sense.

Several of the panels noted that most people viewed the Bay as a living system, and the quality of the Bay is often thought of in terms of the health of this living system. The lithosphere, the hydrosphere, and the atmosphere are considered to be the environment of the biosphere, and it is the interaction between the biosphere and its environment that is requisite for understanding the Bay. The lithosphere contributes the soils with their different particle size distribution and chemistries. It acts as the foundation for the entire system and as a conduit for the subsurface waters. In its own right, it is important to consider the lithosphere because of its exploitation potential in terms of mineral and petroleum resources. It is too easy to dwell on the hydrosphere because, for many, the surface water that constitutes the Bay is viewed as the total definable problem; however, no study of the major water system is complete without considering both atmospheric water and groundwater. One needs only to study the sources, routes, and sinks of pollution in water systems to realize what a complex and dynamic circulation pattern it is. In terms of the Chesapeake Bay as defined, the atmosphere is too large for practical description. Although it is reasonable to expect that atmospheric events occurring as far west as Chicago will measurably affect the Chesapeake Bay, for management purposes, a measurement network design can have much closer boundaries. The atmosphere is essential in describing and studying energy-balance models, primary productivity models, and, as previously mentioned, hydrologic models that involve the Bay.

Finally, the biosphere itself is frequently oversimplified by describing the plants and animals involved in terms of phytoplankton and zooplankton. Many other organisms, including man, play an important role in the interaction between living systems that use the Bay as a habitat and other living systems, such as man, that tend to exploit the resource. Microorganisms must be viewed as both pathogenic, symbiotic, and, in some cases, essential. A good example of a blessing and a curse is the latter category in which nitrogen-fixing organisms are both essential for soil productivity and a source of pollution to water.

## REMOTE SENSING AS A PART OF THE INFORMATION SYSTEM

Figure 1 is a block diagram of an information system concept that was designed specifically for use with remote sensing. It is a closed-loop model and is centrally oriented in that information flows to the management decision block and requirements for information flow from that block.

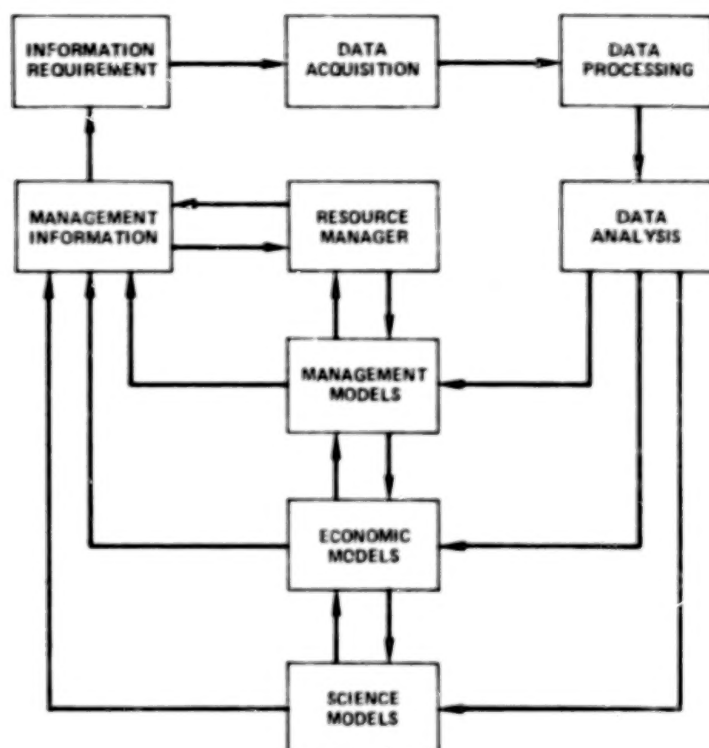


Figure 1. Natural resource management information system concept.

In many organizations, both in and out of the government sector, data is collected simply because it can be acquired. In the development of remote sensing devices, there was an intensive effort to meet the requirements of management decision-makers in the natural-resource field because of the high cost of both satellites and aircraft. In the data processing block, both conventional photo products and more sophisticated and quantitative digital products are prepared and delivered to the analytical group. In the data-analysis block, a variety of methods is available, and many of them are suitable for implementation in an operational scenario. They include conventional photointerpretation with simple light tables, machine-assisted interpretation, and, finally, a fully automated approach using a variety of current computers. The direct recognition of natural surface features, based on their shape alone, is the exception rather than the rule in terrain and surface-water analysis. In these fields, the key to the analysis of the feature is frequently color although the reader will often find the term "multispectral signature." The term is certainly more accurate when one considers that both infrared and microwave sensors are involved in the data-acquisition process. In addition, the interpretation team is invariably made up of natural-resource scientists rather than a team of technically trained personnel. It is the professional background of the team that makes the interpretation of the data possible.

The models are parallel blocks, but the vertical lines between them are meant to imply that there is an interaction between the science, the economic, and the management models. The most popular concept of modeling is that one can reduce all parameters to numerical form for computer processing. Many natural-resource models are numerical; many others are not. The term "model" includes both the numerical form and the *iterative* form in which there is a prescribed sequence to the order of the data so that cause and effect patterns are produced and conclusions are drawn from the analysis of the patterns. As figure 1 illustrates, all three of the modeling blocks may be required for producing information for the management-alternative block. This is as far as the natural-resource scientist goes in producing information for management decisions. In this concept, these alternatives are given to the managers who represent a different entity than the remote sensing resource scientists, and, for the purposes of this panel, it is appropriate to consider that those decisions are state and/or regional management decisions. The decision process can result in a course of action, but that is beyond the scope of this report. However, the process can result in a requirement for additional data for that or future decisions by the management group. The data-requirements block constitutes the feedback loop of the information system and begins the process over again with the acquisition of data to satisfy that requirement.

If there is a unifying theme to the information system concept, it is expressed in the phrase "the convergence of evidence." These words describe both the method and philosophy of the approach. In merely stating the goal of the technology—to provide a current assessment of the status of the Chesapeake Bay—it is necessary to realize that one is trying to monitor and, in some cases, to predict the behavior and the interaction between three of our most dynamic environments—the atmosphere, the hydrosphere, and the biosphere. The convergence-of-evidence approach is in recognition that this is both a complex and dynamic problem and that the sources of input data vary in their precision and in their reliability. The concept implies that there are several input data sources, as indeed there are.

### ECOLOGICAL PARTITIONING

Studies on land systems have resulted in a methodology for partitioning the land into geobotanical landscape units. These represent syntheses of certain key items of knowledge about the area. These variables include the regional distribution of land forms, geology, meteorology, climate, hydrology, and, to some extent, human activity. The interaction of these phenomena produce a base to which specific living resources (such as vegetation and animal life) respond and on which natural processes (e.g., soil formation, erosion, and deposition) work. The purpose of the analysis is to partition the region or country into meaningful ecological units; meaningful in the sense that the units thus defined represent land capability classes in terms of both natural processes and human activity. The stratification is designed to greatly improve both the reliability and cost-effectiveness of all kinds of statistics related to productivity,

land use, and natural resources. It also becomes a spatial data base for the systematic organization of available information about both the natural resources and the dependent society, and it represents a basis for organizing and presenting plans for development programs that are founded on the concept that opportunities and constraints to resource development are usually similar in like ecological regions. Finally, it provides an improved basis for the development of a total resource policy for setting priorities and scheduling program implementation because it gives decision-makers at all levels, both administrative and operational, a perspective of the country or region that simplifies what would otherwise be an overwhelming body of complex detail about the resource and the area.

In performing the ecological partitions, the resource science team is made up of hydrologists, geologists, soil scientists, vegetation analysts, and either an agronomist, botanist, or both and is usually lead by a geographer. The flow of analytical functions performed by the team involves the production of a series of descriptive overlays derived from a combination of remote sensing and collateral data sources. All of the following analyses are performed in the sequence: (1) drainage, (2) surficial materials, (3) geology, (4) soils, (5) vegetation, (6) transportation, (7) cultural features, and (8) existing land use. These eight overlays are then used by the team to generate a land capabilities classification overlay. In the strictest sense, the class boundaries represent ecological partitions. The questions we must ask concerning the water mass of the Bay are: If one is provided a cross-correlation matrix in which temperature, turbidity, color, and salinity have been measured on each matrix cell, do these descriptors uniquely define a habitat (ecological partition) in water? Always? Ever? If the answer to any of these questions is yes, we have the basis of a model. Equally important, we know from experience in the terrain case that, when we have established the boundaries of the various classes or the ecological partitions, we can extrapolate with some confidence point measurements made within the confines of that boundary to the total area encompassed by the boundary; therefore, a point measurement of temperature becomes an area measurement, a point measurement of productivity becomes an area measurement, and a point sample of population becomes an area inventory.

## LANDSAT INVESTIGATIONS

Because there were over 300 investigators in the Landsat program it became essential to construct a key for the coding, sorting, filing, and retrieval of the documents themselves and the significant reports of results derived from the documentation. The access words for the key-sort program are:

- Agriculture/forestry/range resources
  - Crop survey and classification
  - Timber survey and classification
  - Range survey and classification

- Soil survey and classification
  - Soil-moisture monitoring
  - Water utilization - evapotranspiration
  - Stress detection and monitoring
  - General
  - Other
- Land-use survey and mapping
  - Land-use classification
  - Orthographic mapping
  - Thematic mapping
  - Polar-region mapping
  - Human population densities and locations surveys
  - Archaeological, anthropological, and ethnological mapping
  - Transportation systems surveys
  - General
  - Other
- Mineral resources, geological structure, and landform surveys
  - Mineral exploration
  - Petroleum exploration
  - Volcano surveys
  - Landslide surveys
  - Earthquake-zone investigations
  - Geothermal surveys
  - Wind erosion
  - Water erosion
  - Geomorphic and landform surveys
  - Lithologic surveys
  - Structural surveys
  - Mine safety, hazard survey, and disaster
  - General
  - Other
- Water resources
  - Watershed surveys
  - Ground water surveys
  - Estuary and wetlands surveys
  - Limnology
  - Desertification
  - Flood assessment and prediction

- Snow surveys
  - Glacier surveys
  - Lake-ice surveys
  - Reservoir monitoring
  - River monitoring
  - General
  - Other
- Marine resources and ocean surveys
  - Locating biologically rich areas
  - Surveys of current and ocean dynamics
  - Measurement of sea state
  - Detection of navigational hazards
  - Sea-ice monitoring
  - Estuary dynamics
  - Bathymetry
  - Coastal-zone processes
  - Disaster assessment
  - General
  - Other
- Meteorology
  - Mesoscale processes
  - Air-surface interactions
  - Cloud physics
  - Radiative transfer characteristics of the atmosphere
  - Disaster assessment
  - General
  - Other
- Environment
  - Air pollution
  - Land pollution
  - Lake and river pollution surveys
  - Ocean-water pollution surveys
  - Biotic and abiotic degradation surveys
  - Surveys of and degradation from cultural pressures
  - Indicator and sentinel plant species
  - Biome definition and monitoring
  - Ecological equilibrium and dynamics surveys

- Phenology
  - Wildlife habitat surveys
  - Disaster surveys and assessments
  - General
  - Other
- Interpretation techniques development
  - Digital information extraction techniques
  - Interactive image processing
  - Classification and pattern recognition
  - Data-compression techniques
  - Image-enhancement techniques
  - Effects of the atmosphere
  - General
  - Other
- Sensor technology
  - Sensitivity, resolution, signal-to-noise, and error and degradation analyses
  - Data-collection platforms
  - General
  - Other
- Multidisciplinary resources survey
  - National
  - State
  - Regional
  - Other



## **ROLE OF REMOTE SENSING IN DOCUMENTING LIVING RESOURCES**

**Peter E. Wagner, Chairperson**

**Richard R. Anderson**

**Bert Brun**

**Max Eisenberg**

**John B. Genys**

**Donald W. Lear, Jr.**

**Myron Miller**

### **INTRODUCTION**

The group decided not to attempt a systematic development of a species list of living resources of the Chesapeake Bay, although such a list exists (McErlean et al., 1972). Instead, we chose to identify a number of specific problems that show promise of resolution by remote sensing methods.

Although the term "remote sensing" covers all noncontacting measurements, we arbitrarily decided to emphasize satellite imagery in preference to other techniques, such as those that involve data platforms or aircraft flights. Satellite sensing appeared to us to be more nearly unique, more technologically advanced, and more seriously underutilized. In the situations noted below, however, more traditional remote sensing with conventional aircraft definitely retains value in existing or even suggested programs.

The work began with a review of the report made by a similar body of a conference on remote sensing sponsored by the National Aeronautics and Space Administration (NASA), Wallops Flight Center (McErlean, 1971). This report contains a topical outline on extractable biological resources and an interesting paper by L. E. Cronin. Although for the most part it remains valid today, a number of noteworthy technological advances have taken place in the interim, including:

- **Laser applications.** Kim (1973) has mapped chlorophyll distributions in Lake Ontario by means of laser-excited fluorescence. Time-resolved laser backscattering (Lidar) shows considerable promise for remote measurements of turbidity in the photic zone (that is, below the water surface (Hickman and Hogg, 1969; and Hickman and Wilkerson's paper in this document and references therein)).
- **Multispectral Scanning.** Johnson (1977) has employed improvements in this technique for mapping chlorophyll distributions in the coastal zones. Hovis also discussed the subject at this Conference. Menhaden produce oil slicks that are detectable by multispectral imagery (Lear, private communication, 1977).



- **Acoustic Sensing.** Although acoustic sensing is not a remote airborne method, it has been used successfully in several kinds of biological investigations, both experimental and commercial.

Although there are areas such as those cited above in which remote sensing technology has either delivered, or needs only specific program definition to be able to deliver, data helpful to documentation of living Bay resources, the state of the art does not permit data gathering in some other important areas.

Included in the second group are determination of dissolved nutrients, heavy metals and organic biocides, bacterial data, dissolved oxygen, BOD, and, in general, significant physical and chemical data from below the surface of the water (although lidar techniques show promise in this last area). Since these data are of obvious vital importance to biological processes in the Bay, encouragement should be given to experimentation along these lines. In the interim, various *in situ* techniques and equipment will continue to be used.

### **SELECTED TOPICS FOR REMOTE SENSING OF BIOLOGICAL RESOURCES**

This discussion turned to specific cases of known or potentially useful applications of remote sensing in assessing biological resources.

In selecting items for inclusion, we chose to retain only topics that satisfied one of two criteria: they were already reduced to practice or were entirely feasible, and/or they were so important in an ecological sense as to justify inclusion even when present technology was believed to be inadequate.

After discussion it was decided that the most usable remote sensing techniques now relate principally to the measurement of population fluctuations in aquatic systems. We considered this measurement from two broad standpoints: (1) the flora of the Bay, and (2) the fauna.

#### **Flora**

Gross changes in population structure and geographical location are considered to be a potential indicator of degradation in aquatic systems.

Uhler (1977) recently stated that the following sequential episodic events have been recorded during and after severe degradation of lakes and estuaries: (1) frequent and consistent algal proliferation, (2) large and periodic swings in abundance of rooted aquatic vegetation with eventual reduction in their areal expanse, and (3) replacement of valuable rooted aquatics with less desirable species.

We believe that remote sensing can play an important part in defining population changes in aquatic vegetation in the Chesapeake Bay. The role of remote sensing is of two general types:

#### *Direct Sensing of Aquatic Plant Populations*

This involves: (1) qualitative estimation of plankton blooms and species excursions from Landsat; and (2) quantitative detection of chlorophyll with multispectral scanners and lasers, with a potential capacity for separating inorganic and organic particulates in the water column.

#### *Sensing of Water Quality*

This involves sensing of the following water-quality parameters that directly impact aquatic vegetation:

- **Suspended Particulates or Turbidity.** Particulate matter alters light transmission in the water column that can reduce the areal expanse of rooted aquatic beds and increase certain phytoplankton populations. The following dynamic aspects of suspended materials need to be known and may be at least qualitatively identified from a remote platform:
  - **Sources of suspended Particulate Matter.** We need to know whether these sources are the result of runoff from a contiguous land surface or the result of water turbulence in the Bay proper. If we can identify sources of this material, we may be able to infer the composition of materials within the sediment.
  - **Distribution and fate of suspended materials in the Bay.** Where do they go and where do they stop? What can we infer about the distribution of these suspended materials from circulation patterns in the Bay?
- **Other Water-Quality Parameters that Impact Aquatic Vegetation.** We feel that, at this time, a satellite platform has relatively limited use for temperature, salinity, and sea state. At the present time, these require aircraft platforms.

The impact of changes in salinity and temperature and the erosive aspects of wind-generated waves must be considered in assessing distributions of rooted aquatic species.

#### **Fauna**

The fauna of the Bay is a feature of the ecosystem that offers an excellent opportunity for interface with man (e.g., through commercial and recreational fishing). Parameters such as temperature and salinity that influence the floral regime also influence faunal distribution and abundance. Therefore, the remote sensing of these parameters will be of general biological value in understanding changes in the Bay fauna.

In addition, relationships exist between flora and fauna that are vital to the stability of the entire ecosystem. Primary production forms the basis of the food chain; therefore, changes in the makeup of the flora on the Bay result in faunal changes. An example is the decline of submerged aquatic vegetation, providing less food for certain waterfowl and less cover for various invertebrates that represent other food sources to fish or waterfowl.

Thus, a remote sensing program emphasizing documentation of turbidity in the Bay relative to floral changes can provide valuable inferences toward an understanding of faunal change. In addition to the foregoing direct examples, indirect effects of turbidity can occur. For example, when dead material from a plankton bloom decays, the dissolved oxygen needed by various faunal species can be depleted. The Bay becomes essentially anoxic below a depth of 4.6 meters (15 feet) during the summer.

Of interest to man are the changes in the species of fishes in the Bay (e.g., the increase of blue fish and the decrease of striped bass). Better documentation of the temporal/spatial distribution of various species would therefore be helpful. This could be done by means of sensing by low-flying aircraft using conventional photography or, if resolution and timing periodicity permit, by satellite imagery. An example of useful data would be tracking of fish schools; but, in addition, some means of obtaining signatures of different species would be needed (e.g., the detection of specific oil slicks by multispectral analysis).

Other information regarding distribution and habitat of fauna can be obtained from different tools in the arsenal of remote sensing devices, such as acoustic sensors and lidars. Acoustic sensors have already proved their value as fish finders and in determining bottom types. Lidars also show potential for bottom-type classification.

Major man-induced perturbations, such as oil spills, can be documented by remote sensing devices to ascertain their effects on fauna. Satellite platforms can perform surveillance using visual bands or other scanning modes; and, once a pollution emergency is identified, low-flying aircraft can provide more detailed information, such as numbers and areas of fish or bird kills.

## RECOMMENDATIONS

The working group believes that the immediate role that remote sensing, particularly from satellites, can play in documenting living resources in the Chesapeake Bay is in assessing population distribution and fluctuations of aquatic plants. We strongly recommend that the following projects be undertaken as soon as possible:

- An investigation of the archival photography of the Chesapeake Bay should be undertaken to attempt an estimation of excursions in rooted aquatic populations over the last 30 to 40 years. To some extent, this recommendation is being carried out by J. C. Stevenson at the University of Maryland.

- There should be an investigation of satellite data to determine sources, distribution, and fate of suspended particulate matter. We believe that the satellite data we now have, particularly that from Landsat, could give some indication of the dynamics of the suspended materials in the Chesapeake Bay.
- Possibly based on information generated from the project previously outlined, we believe that land use should be catalogued on a watershed or subbasin basis in the Chesapeake Bay. We could then possibly infer organic and inorganic content of runoff on a watershed basis. In recent years, satellite data has been valuable in land-use studies. The current Maryland geographical-based information system could be of very definite value to this project.
- Field research is needed for obtaining a better data base in certain subject areas. A subsequent step should be to develop techniques and instrumentation to gather such data from remote platforms. Projects would include the assessment of the tolerances of important submerged grasses to salinity, temperature, pesticides, turbidity, heavy metals, and other factors. Also, more documentation and assessment are needed of the impact of submerged grass population excursions on important faunal components of the Bay.

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## USE OF REMOTE SENSING IN FACILITY SITING

**Milton L. Moon, Chairperson**

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### INTRODUCTION

Maryland law currently requires environmental impact predictions for electric power-generation facilities proposed within the State and impact assessment of operating plants. These studies are extensive, and it can be expected that similar studies will ultimately be required for other major facilities (e.g., refineries, pipelines, oil-loading facilities, and other industrial facilities). It appears reasonable to expect that environmental studies related to these facilities will have many characteristics in common with the methods used in power-plant siting.

Because many of these studies must be done before plant construction, they are clearly predictive. The methods currently in use consist of: (1) characterization of the present environment, (2) analytical modeling of the operation of the proposed plant in the environment, (3) prediction of the resulting environment or environmental change, and (4) a determination of conformance or nonconformance of the result with environmental standards. Data and predictions must be quantified whenever possible. The validity of the data must be protected by adequate "ground-truth" verification.

The environmental data now needed to support this work are obtained from *in-situ* instrumentation, sampling representative points in the neighboring environment by "accepted" instrumentation. For example:

- Meteorology data utilizes towers (nominally 90 meters (300 feet) high) instrumented at three levels to obtain wind direction, velocity fields, temperature, temperature lapse rate, and humidity.
- Receiving water properties are determined by dye studies, current meter studies, time-sequence temperature histories, and similar methods.

The data-acquisition instrumentation is considered to be the "best available" and, when used properly, produces highly accurate data. On the other hand, because the data-acquisition methods are labor intensive, the sampling stations are limited. The environmental variability of the site is not easily determined. A continuing search for improved methods of data acquisition is important so that the most meaningful product can be produced at the most

reasonable cost. It is in this spirit that we ask, "Can remote sensing be used to provide data for use in site-evaluation or monitoring programs to provide evaluation products comparable in quality (validity) to the current products, and would such data acquisition possibly provide improved capabilities?"

### REMOTE SENSING TECHNIQUES APPLICABLE TO SITE EVALUATION

Parameters of the local and/or regional lithosphere, hydrosphere, and atmosphere may have an impact on the selection of a facility site or may be affected by the construction and operation of the facility. It is important to define which parameters are important to, and necessary for, an environmental impact assessment. Remote sensing techniques can then be examined as potential measurement devices of these parameters. Table 1 lists the parameters often used for site evaluations, which may be considered as candidates for remote sensing applications. Although the list is not complete, it includes most of the parameters currently considered to be significant.

The committee then attempted to list the equipment capable of measuring these environmental parameters. These remote sensing devices are listed down the side of table 1. Again, this is not a definitive study but does indicate a number of areas in which present and future sensor systems should be seriously considered for application to siting-parameter measurements.

Several federal government organizations have recognized the need to focus their remote sensing capability on the solution of Earth resource problems. Commitments have been made to research and development (R&D) efforts for improved sensors. Undoubtedly, the list of sensors will grow, and applications will continue to be developed to advance the state of the art or to serve as prototypes for future sensors.

The new class of instruments includes, but is not necessarily limited to, radar (special purpose), lidar, radiometers, acoustic sounders, multispectral scanners, and special-purpose sonars. These instruments are characterized by their ability to provide measurements at points separated from the instrument by considerable distances and, even more important, may make it possible to obtain values of the measurement throughout a volume (i.e., a nearly synoptic field of data) rather than the spot sampling obtained by present devices. (This is an important characteristic that must be "traded-off" against the deterioration of individual data-point accuracy that may occur.)

Siting studies already use some types of remote sensing to a modest degree, and it can be expected that such uses will be continued and expanded. Area screening for the location of possible sites is normally based on map studies supported by aerial photography and ultimately by on-site inspections. In addition, aerial photography, infrared satellite and aircraft scans, and side-looking radar data are used extensively in searching for lineaments that *may be*



Table 1  
Remote Sensing Techniques for Siting (status and availability)

		Parameters Required for Facility Siting																		
		Atmospheric			Hydrologic							Lithospheric								
		Wind Velocity/Patterns	Particulate/Aerosol Burden	Temp/Pressure/Humidity Profile	Water Circulation/Turbulence	Aquatic Plant Life	Fresh Water Supply	Thermal Profiles/Surface Temp.	Sedimentation Transport	Bathymetry	Local Water Use	Fault Structure	Flood Plain	Drainage	Land Use/Cover	Wildlife Habitat	Seismic Activity	Bottom Topography	Sulfur Burden	Aquatic Fish Life
Commercial	Spectrometers		X																	
	Sonar								X											X
	Seismometers																X			
	Aircraft multi-spectral scanner (MSS)					X	X	X	X		X		X		X	X				
	Aircraft cameras/film/filters					X	X	X	X		X	X	X		X	X				
	Thermal radiometers		X	X				X												
	Sonar (sidescan)									X								X		
Demonstrated	Landsat-1 and -2 MSS		X				X		X			X	X	X	X	X				
	Return-beam vidicon (RBV)														X					
	Acoustic probes	X		X																
	Radar	X			X															
	Lidar		X																	
	Aircraft camera systems								X											
Developmental	Landsat-C MSS		X					X	X			X	X	X	X	X				
	RBV															X				
	Microwave radiometer															X	X			
	Lidar	X <sup>a</sup>	X	X <sup>b</sup>						X										
	Acoustic probes			X	X				X											
	Radar	X			X	X														
	Seasat				X															
Conceptual	Landsat-D MSS		X					X				X			X	X				
	Lidar	X <sup>c</sup>	X							X										
	Acoustic probes			X	X															
	Radar														X	X				

<sup>a</sup> Work done in NOAA laboratory.<sup>b</sup> Dye studies.<sup>c</sup> (SF<sub>6</sub>)



indicative of geological formations that could preclude site acceptability for certain uses (e.g., nuclear power plants). Geological features detected in this manner must be inspected carefully on site by a skilled geologist, and many will require seismic studies to determine whether or not they are "capable" faults as defined by the Nuclear Regulatory Commission (NRC) regulations. Such seismic studies are a well-developed form of remote sensing using acoustical techniques.

Monitoring programs have also made use of remote sensing. Recent field work by the National Aeronautics and Space Administration (NASA) lidar group from Langley Research Center, Virginia, at the Morgantown Steam Electric Station has proved invaluable for air dispersion model verification programs funded by impact assessment.\* The lidar measured the characteristics such as the three-dimensional aerosol-plume spread and the detailed plume rise velocity that could not be obtained by conventional techniques. A further lidar investigation in cooperation with NASA planned for Spring, 1978, will make use of an  $\text{SO}_2$  measurement capability to check for  $\text{SO}_2$ /aerosol-plume separation and to aid in model-validation studies for complex terrain. In addition, the possible use of an airborne dye-fluorosensing device and a remote wind-sensing technique is being explored with the appropriate agencies (NASA and the National Oceanic and Atmospheric Administration (NOAA), respectively) for future monitoring applications.

The committee also attempted to assess the availability of the equipment and/or the status of the application of that measuring technique to a particular parameter; hence, the designations commercial, demonstrated, developmental, and conceptual, which are defined as follows:

- Commercial—off-the-shelf, can be purchased or services contracted
- Demonstrated—on-the-shelf, available but technology not transferred to commercial sector
- Developmental—hardware research in progress
- Conceptual—theoretical research in progress

It is observed that equipments off-shelf, on-shelf, in development, and in concept offer possibilities for improved data-acquisition programs and should be carefully exploited. However, the choice of a remote sensing device over conventional instrumentation, or the choice of one remote sensing device over another, for measuring a particular parameter may be influenced by factors other than status and availability. Criteria for acceptability of a given technique cannot be fully developed within a 3-day workshop; however, the following general statements can be made:

- Data requirements must be carefully established with relation to the models used. Some degradation of data at any particular sample point (relative to present

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\* Information concerning the cooperative program between NASA and the Maryland Power Plant Siting Program was provided by Dr. P. Massicot, Chief, Power Plant Siting Program.

methods) may occur, but the possible value of data fields as compared to point data must be carefully factored in (i.e., increased resolution and/or accuracy versus large synoptic view).

- The use of such data must yield some combination of: (1) comparable quality at reduced cost, (2) better quality evaluations at comparable cost, and (3) reduction of data processing or analysis costs.
- The credibility of such data for these uses must be established by a systematic program of ground-truth verification for each new data-acquisition device.

### SIGNIFICANT PROBLEM AREAS

A number of problem areas that are in series with the successful introduction of these techniques have been identified. Our list is probably not complete, but, as a minimum, these problems must be addressed:

- The adversary nature of the decision process for facility approval requires that the credibility of new measurement methods be carefully established in both a scientific and legal sense. To be blunt (but we think realistic), it must be understood that, in an adversary hearing, there will be no hesitation on the part of the legal system to discredit remote sensing data if it will result in winning a particular advocacy position. Irreparable damage to the credibility of remote sensing methods can be done unless the introduction of such methods is supported by adequate ground-truth data based on generally accepted instrumentation. This appears to imply that:
  - Measurement standards for remote sensing will probably have to be established in a formal way.
  - Legal advice on the strategy of introducing these methods would probably have to be established in a formal way.
  - Legal advice on the strategy of introducing these methods would probably be useful.
  - For some period of time, approved data-acquisition methods must be used in parallel with the remote sensing instruments.
- The split responsibilities of institutions around the Chesapeake Bay make the introduction of new technology more difficult. The Chesapeake Biological Laboratory (CBL), Virginia Institute of Marine Science (VIMS), Chesapeake Bay Institute (CBI), Corps of Engineers, Applied Physics Laboratory (APL), Martin-Marietta Corporation (MMC), etc., have all selected methods of data acquisition with which

they feel comfortable and for which they have acquired the necessary equipment. Leaving aside for the moment the problem of convincing an organization of the reliability of a new technique, the division of responsibilities (and thus funding) limits the equipment that could be purchased. For example, a system costing \$250,000 could not be justified by any one organization if it was to be used only once or twice per year. However, on a regional basis, the need for such a system might be apparent. At the present time, no sharing mechanism exists.

- The most important limiting factor, however, appears to be limitations in the present method of technology transfer from research to user. This condition is manifested through the following:
  - Federal research and development efforts usually stop after a brief demonstration program showing the capabilities of a device. Few efforts are made to transfer the technology to a user-oriented rather than a research-oriented device.
  - The equipment available from commercial sources is often in a late developmental phase. Few organizations can afford the luxury of investing in equipment that is largely untested.
  - Because of the cost of many of these devices, the commercial market may be extremely limited. Thus, private companies are reluctant to invest funds to engineer products they may not be able to sell.
- Finally, the adversary relationship in which this data will be used is costly. It must be recognized that states and local governments are not well prepared to accept the additional costs posed by the duplication of data acquisition during the proof phase.

## CONCLUSIONS AND RECOMMENDATIONS

As it exists, the "Status and Availability Matrix" on Remote Sensing Techniques for Siting is crude and not very useful. To those who are seeking instrumentation for collecting siting environmental data for evaluating data-collection techniques as a basis for a position in an adversary relationship, an expanded version of this matrix would be valuable. As a minimum, the expansion should enable preliminary tradeoffs to be made on the basis of parameters such as the limitations of techniques, specifications of instrumentations, spatial and temporal scales of applicability, and costs of hardware, deployment, and data preprocessing. Its most useful form is probably a set of large matrixes with supportive documentation for each entry. The working group does not plan to assemble such a series of matrixes for publication. However, this would seem to be an ideal project for an individual working under a short-term appointment, such as a co-op student, a summer fellow, etc.

Federal R&D laboratories should be encouraged to work more closely with production and marketing industries to transfer remote sensing technology devices that can be economically produced and that can and will be bought and used by users.

NASA has recognized the need to work more closely with users in order to transfer remote sensing technology. To accomplish this, NASA has established three Regional Applications Training Centers (RATC). The RATC at the Goddard Space Flight Center is responsible for conducting projects initiated by users in the eastern region of the United States. Problems associated with establishing the validity of Landsat satellite data in litigation proceedings are discussed in this report. Projects directed at establishing the legal credibility of remote sensing data are of the type that the RATC could undertake. Also, the RATC would be interested in demonstrating the application of Landsat data to generating environmental impact assessment statements required by law for major facility sitings. Short-term projects of this nature should be brought to the attention of the RATC.

The necessity of duplication of data acquisition during the development of new standards—especially in the proof phase of remote sensing in applications with legal implications—should be brought to the attention of funding agencies for their budgetary planning process.

Finally, the interest of state agencies, as described in this report should be recognized, and cooperative federal/state/contractor programs should be utilized when feasible to obtain further user experience with the remote sensing methods and equipment.

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# **ROLE OF REMOTE SENSING IN DOCUMENTING LAND USE AS IT AFFECTS THE BAY AND BAY USE AS IT AFFECTS THE LAND**

**William F. Rhodes, Chairperson  
John M. Garber  
John M. Hill  
Walter E. Raum**

## **INTRODUCTION**

This group discussed two problems: (1) the role of remote sensing in documenting land use as it affects the Bay, and (2) the need for a "clearinghouse" for all remotely sensed information that has been and will be acquired over the Bay and its drainage basin.

## **REMOTE SENSING IN DOCUMENTING IMPROPER LAND USE**

A high degree of scientific, engineering, and technical expertise in water testing has been developed and amply applied to documenting the quality of the Bay water. However, although a comparable expertise in remote sensing exists, it has not been applied to locating, identifying, and monitoring the causal factors that affect the Bay water. The principal source of these causal factors may be nonpoint, or diffuse, pollution caused by improper land-use practices. The remote sensing technology required for locating, identifying, and monitoring these nonpoint pollution sources is available; it need only be applied.

## **CONCLUSIONS**

Airborne remote sensors can provide "pictures" of the Earth's surface ranging from a 26,000-km<sup>2</sup> (10,000-mi<sup>2</sup>) view of the entire Chesapeake Bay down to a 9.3-m<sup>2</sup> (100-ft<sup>2</sup>) view in which the lettering on a beer can is legible. Within this range, any identifiable pollution source can be identified. The mechanics of a land-use survey inventory of nonpoint pollution sources from remotely sensed imagery are not complicated or difficult. However, a basic knowledge of image interpretation techniques, experience in recognizing specific signatures (identifying features), and the ability to transfer image data to a map are required.

A detailed land-use survey can be a laborious, time-consuming task, but is a necessary step in isolating the causal factors related to water degradation. The adage "you are what you eat" could be applied to the quality of the Bay water. It is what it eats or, rather, what it is force-fed, and most of what it is fed (point and nonpoint pollution) comes from the land that lies within its drainage basin. The bottom line in a nonpoint pollution source inventory is the polluter, regardless of its size, type, or origin. It may be a ranch, a small farm, or an individual

field; it may be a sewage-treatment plant for a large city or an individual outhouse; it may be a bad farming practice such as overfertilization, overirrigation, lack of contouring, or overgrazing; it may be runoff from a commercial feedlot, a corral, a shopping-center parking lot, or an auto graveyard; it may be raw waste from animal access to streams; or it may be improper maintenance of irrigation canals and drains. But whatever the source and the size, the polluter must be identified before remedial action can be initiated.

The feasibility of using airborne remote sensing systems to determine the influence of land use on water quality is substantiated, if only by the timely, expeditious locating and identifying of nonpoint pollution sources (land-use practices) that are afforded by the overhead view. Although the art of direct determination of water-quality criteria by remote sensing systems is in its infancy and findings are inconclusive or limited, many tasks can be accomplished through remote sensing in isolating causal factors that affect water quality.

The use of remote sensing systems will normally save time and money when compared to the cost of collecting data by ground survey methods and will often provide data that cannot be obtained by ground survey methods. The perspective afforded by airborne remote sensing systems is unique. What a person sees from ground level can be severely limited by terrain features, structures, and vegetation. From overhead, very little escapes detection by remote sensors, which are limited only by the ability and experience of the interpreter and the quality of the imagery. To identify through ground survey only the causal factors needed to establish criteria to accurately measure and predict the effect of land use on water quality would be prohibitively time consuming and expensive.

### **Recommendation**

Although water sampling is the only means to conclusively qualify and quantify contaminants in water, remote sensing is the most efficient means of locating, identifying, and monitoring the causal factors (nonpoint pollution sources) that supply the contaminants. Hence, this workshop recommends that remote sensing be included as an integral phase of any comprehensive water-quality project concerning the Chesapeake Bay.

### **REFERENCE CENTER FOR REMOTELY SENSED INFORMATION**

Most groups that participate in Chesapeake Bay programs have specialized capabilities to do environmental studies. However, it is doubtful if any group has the capability to solve all the problems that affect the Bay. Some groups, such as the National Aeronautics and Space Administration and the Environmental Protection Agency, have specialized capabilities in remote sensing technology whereas others, such as the Chesapeake Research Consortium, Inc., have specialized capabilities in analyzing water quality in the field or in the laboratory. Although these and other groups active in studying the Chesapeake Bay have like capabilities, all too often their facilities, objectives, and areas of interest are insular. Generally, each group



works independently, using imagery acquired to meet a specific need. Also, each project addresses a specific problem for a single requestor, thus limiting the distribution of the report. Imagery is generally used once and then shelved to be lost forever except in the minds of a few. No system now exists that permits a complete and current interchange of information concerning the status of imagery acquisition in the Chesapeake Bay region.

### **Conclusions**

There is a need for a reference Center—a "clearinghouse" that would function as an information interface between the federal, state, county, academic, institutional, municipal, and private groups that are working on Bay problems.

This Center should contain several types of user information that would include, but not be restricted to, an index of all imagery that has been acquired over the Bay and its drainage basin; a complete listing of all reports compiled on the Bay; training facilities for analyzing imagery; and guidelines for acquiring imagery, including information on sensors, platforms, films, temporal considerations, scales, and resolution.

This Center could also provide a reliable referral service for supportive data in other disciplines, such as political considerations, mapping capabilities, population dispersions, and land-use planning.

The communications medium for information dissemination could be a newsletter issued at a frequency that would preclude duplication in imagery acquisition and analysis and in reporting.

### **Recommendation**

This workshop recommends that a reference center—an information "clearinghouse"—be formed through which users could easily, expeditiously, and confidently determine what remote sensing data and reports on the Chesapeake Bay Region exist.



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## **ROLE OF REMOTE SENSING IN BAY MEASUREMENTS**

**John P. Mugler, Jr., Chairperson**

**John P. Godfrey**

**G. Daniel Hickman**

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**Albin O. Pearson**

**Kenneth N. Weaver**

### **INTRODUCTION**

This working group considered three major categories of remote measurements that would serve to better characterize and further the understanding of the ecology of the Chesapeake Bay: (1) remote measurements of a number of surface or near-surface parameters for baseline definition and specialized studies, (2) remote measurements of episodic events, and (3) remote measurements of the Bay lithosphere.

### **REMOTE MEASUREMENTS FOR BASELINE DEFINITION AND SPECIALIZED STUDIES**

Techniques and sensors for remote sensing of environmental quality from aircraft and satellites have been under development for many years. Only a few are now available as "off-the-shelf" hardware or are being used with sufficient regularity to provide synoptic coverage of the Chesapeake Bay. For example, camera systems are readily available at reasonable cost and provide useful information. Data banks for photographic imagery exist at several locations, such as at the National Aeronautics and Space Administration's (NASA's) Wallops Flight Center and Ames Research Center, as well as at the Department of Interior's Sioux Falls, South Dakota, installation. Most of this photographic imagery, obtained in support of small, individual investigations, does not provide an overall time-sequenced coverage of the entire Bay.

In general, the types of sensors available consist of two major categories: passive and active units. In the former category are the photographic systems and various forms of radiometers that detect reflected sunlight, emitted thermal radiation, and solar-induced fluorescence. The active systems are primarily lasers that detect similar phenomena but are not dependent on sunlight because they provide their own source of light energy. This feature provides these systems with a capability for viewing in the presence of clouds or at night.

Remote sensors can measure only a portion of the quantities required for understanding the Chesapeake Bay. At present, the capabilities that are well understood include the determination of water-surface temperature, suspended sediment gradients, chlorophyll (under certain conditions), spills of various pollutants such as oil, changes in the water/land interface, wetland mapping, various land-use phenomena, and factors related to climatology studies.

Effort is now underway at several government agencies such as the National Oceanic and Atmospheric Administration (NOAA), NASA, Environmental Protection Agency, U.S. Corps of Engineers, and U.S. Departments of Agriculture, Transportation, and Defense to develop and apply new remote sensing techniques to meet a number of varying requirements. A table listing many of these techniques is contained in the Facility Siting Working Group report.

It is pointed out that, although remote sensing is a valuable tool for assessing the state of the Chesapeake Bay, it is not a panacea for all measurements. Obvious limitations are those imposed by weather and spatial resolution, but also of importance in some instances is the fact that measurements in water are limited to the zone near the surface. For many remote sensing applications, it is also essential to provide nearly simultaneous surface-truth measurements for calibration and correlation of the remotely sensed data. The remote sensor has the obvious advantage of providing a synoptic view of large areas and essentially filling in the data required between surface measurements.

Although the technology for obtaining the measurements previously mentioned exists, its application for operational monitoring of an area such as the Chesapeake Bay is not presently contemplated by the individual organizations involved in remote sensing activities. It is suggested that a central planning organization be structured to develop an overall approach for investigating the Chesapeake Bay. This group should incorporate the efforts of all parties involved in the Chesapeake Bay into a single coordinated program. Many of the organizations presently involved in remote sensing research may be induced to perform repetitive measurements in the Bay area as a part of their routine investigations. Unfortunately, most of the organizations that are developing remote sensing techniques are not operational groups providing support services that could compete with the private sector. Periodic experiments, with exchange of information, may be attractive and may offer sufficient reason for joint participation. Note also that most of these organizations have ongoing programs with specified limited resources that would permit only limited initial participation. A coordinated overall plan would assist the various organizations in their individual planning to increase participation if warranted.

### REMOTE MEASUREMENTS OF EPISODIC EVENTS

Episodic events result in essentially unplanned step-function inputs of foreign substances into the system in short periods of time. These events include oil and hazardous materials spills, fresh water runoff from major storm systems, and sediment and debris runoff from land-use practices.

The ability to document and monitor episodic events in major water bodies like the Chesapeake Bay generally ranges from poor to nil; not necessarily because of lack of technology, but generally because of a lack of clearly established responsibilities and commitment of resources by an appropriate organization. This institutional-arrangement situation should

be addressed by an appropriate body. The discussion herein is focused on the availability of remote monitoring technology.

Remote monitoring technology for documenting and monitoring episodic events falls generally into categories of commercially available techniques, developmental techniques, and conceptual techniques. Because the full spectrum of remote techniques is discussed elsewhere in this document, it will not be repeated here. A first step to be taken is to develop arrangements so that existing remote sensing techniques (black and white, natural color, color infrared, and multispectral photography) can be routinely used to document and monitor episodic events. Only after the contributions of existing techniques are fully understood and appreciated by the responsible parties can the improved monitoring capabilities of the emerging developmental and conceptual techniques be evaluated in the proper perspective.

The *status quo* for monitoring episodic events in the Chesapeake Bay is haphazard to chaotic. When an event takes place, many organizations feel a responsibility to do something and initiate some monitoring activity that is usually uncoordinated with other interested parties. As might be expected, the results are usually fragmentary and generally ineffective. There may be some hope on the horizon. The U.S. Coast Guard (5th District, Portsmouth, Virginia) is now developing a contingency plan for response to episodes in waters under their jurisdiction, which includes the Chesapeake Bay. Possibly the steering group for this conference or some other organization with major responsibilities in the Bay could influence the Coast Guard to provide the airborne platforms and equipment for routinely documenting and monitoring episodic events using existing technology. If this could be arranged, a data base for analysis and future research would be available. As the data base enlarges, and if meaningful analysis is conducted by interested parties, the usefulness of remote monitoring in managing and abating episodes will become evident. Similarly, the additional contributions of developmental techniques can be realistically assessed.

## REMOTE MEASUREMENTS OF THE BAY LITHOSPHERE

Remote sensing methods are perceived by the Earth scientists as tools that provide some additional clues on the structure, composition, and spatial relationships of the Earth's crust. These methods are of maximum utility when they support and supplement ongoing activities in geologic mapping of the Earth's surface and subsurface using direct physical measurements or *in situ* sensors (ground truth). Earth science applications of remote sensing methods are generally not as time dependent, and there is not as much need for real-time data as in other disciplines. Some exceptions to this generalization are the monitoring of earthquakes, volcanism, and catastrophic meteorological events.

In the Chesapeake Bay region, the following geologic processes and features are best suited for information enhancement by remote sensing methods:

- Rates of sedimentation in the Bay
- Rates of erosion of Bay shorelines
- Spatial distribution and geometry of aquifers
- Mapping of Karst terrain (sinkholes)
- Mapping of fracture patterns

Taking each of these processes or properties in turn, the following paragraphs outline some things that have been done, are being done, and need to be done in remote sensing applications.

### **Rates of Sedimentation**

With the exception of very broad scale sampling and relatively localized investigations, our knowledge of the distribution and three-dimensional relationships of the bottom sediments of Chesapeake Bay is primitive. A study is now underway to establish baseline data on the geology of the Bay bottom in Maryland. This investigation will use both direct sampling methods as well as remote sensing to map Bay bottom sediments.

Present status of remote sensing:

Method Used	Line Kilometers Covered	Percent of Maryland Section of Bay Surveyed
3.5- and 7.0-kHz transducers 700-joule minisparker	900	15% (approx.)

In addition to mapping the distribution of the bottom sediments, techniques (both remote and direct) in this investigation will provide a baseline on geologic rates of sedimentation to compare with man-affected rates over the past several centuries.

Two remote sensing techniques that are not presently part of this project but that would add significantly to the data base are side-scan sonar and deep-penetration seismic profiling.

As demonstrated in several pilot areas, side-scan sonar appears to be capable of delineating oyster bars and current features in the bottom sediment and, to some extent, can discriminate between sediment types (mud versus sand).

Deep seismic profiling is important in correlating aquifers on the western shore with those on the eastern shore.

Modern bathymetry of the Bay bottom is also vitally necessary for determining historic sedimentation rates by comparing modern bathymetry with previous bathymetric surveys. Perhaps new remote sensing techniques such as lidar will be helpful in generating accurate

bathymetry in a cost-effective manner. This group recommends that an attempt be made to convince the National Ocean Survey, NOAA, to schedule a complete bathymetric survey of the Chesapeake Bay. Present bathymetric maps are out of date and of various vintages in different sections of the Bay.

#### **Rates of Erosion of Bay Shorelines**

Erosion rates along the shoreline of the Chesapeake Bay vary from almost stable shorelines to linear erosion rates of tens of meters per year. An atlas of Maryland shore erosion that characterizes erosion of Bay shorelines from 1848 to modern times is available. Mapping is on a scale of 1:24000.

Remote sensing from aircraft has been used to determine rates in rapidly eroding areas. Yearly flights using sensors that clearly discriminate the land-water interface, supplemented by flights after severe storms, should be programmed to adequately monitor existing conditions. A ground-truth network (baseline stations) has been established in the Maryland section of the Bay. Episodic sensing as described earlier in this report would be helpful in monitoring storm events.

#### **Spatial Distribution and Geometry of Aquifers**

Ground water is the primary supply (and virtually the only supply) of fresh water in the coastal plain in the Chesapeake Bay region. The productivity of aquifers and the quality of ground water is mainly determined by the lateral extent, thickness, depth, mineralogy, and size distribution of the sedimentary formation that contains the aquifer. Aquifers are mapped in the subsurface by both direct means (drilling and examination of extracted materials), *in situ* sensors (downhole geophysical logging), and remote sensors (seismic methods).

Subbottom profiling as previously described has already located paleochannels (sub-Bay bottom sediment-filled channels) that may have application to ground-water supply. If these channels can be delineated and traced to land areas of the Eastern Shore, additional exploration on land may lead to significant sources of fresh water. A paleochannel has been discovered near Salisbury and is now producing water for the Salisbury area.

Aquifers associated with paleochannels are usually water-table aquifers. Deeper penetration seismic techniques as previously described would be useful in delineating deeper artesian aquifers and would also contribute valuable boundary conditions for digital simulation models of coastal-plain aquifers that are now being developed.

Application of the seismic remote sensing technique to very shallow waters of creeks and small estuaries would be invaluable in subsurface investigations. Many creeks on the Eastern Shore could be used to run seismic profiles and thereby obtain information on water-table and artesian aquifers. Unfortunately, the state-of-the-art in seismic reflection profiling cannot compensate for the multiple-reflection problem in shallow waters. This may be a fruitful

area for further research and development. Cooperative relationships with the U.S. Geological Survey are being sought in this area.

### **Mapping Karst Terrain**

The Chesapeake Bay drainage basin contains broad areas underlain by limestone formations. Because limestone is very soluble, solution cavities are formed in the shallow subsurface. Surface materials collapse into these cavities and sinkholes are formed.

The location of sinkholes and areas of potential sinkhole development is extremely critical for many engineering and land-use applications (siting of reservoirs, farm ponds, large structures, and ground-water development). Withdrawal of large amounts of ground water in a limestone terrain has the potential of accelerating sinkhole development. It is therefore important to attempt to find a tool for locating areas of potential sinkhole development.

Remote sensing methods such as thermal infrared and near infrared have been used to successfully delineate such areas. Because these features tend to be fairly small (less than a meter to perhaps 10 meters in diameter) resolution has to be high so that low- or medium-altitude aircraft surveys would be the most applicable. Moreover, time of survey would be important because the best results may be obtained after a heavy rainfall.

Very little effort has been expended on remote sensing applications to mapping Karst terrain in the Chesapeake Bay region. Because it has good promise of yielding useful results, this method should be applied broadly to the limestone areas of the basin. Extension of the episodic sensing arrangements to cover planned events such as this would be highly desirable.

### **Mapping Fracture Patterns**

Fractures (joints, faults, and bedding planes) are important geologic features having applications to ground-water availability and in assessing geologic hazards. In some cases, broad-scale fracture patterns are recognizable in satellite imagery, as well as smaller scale features in aircraft imagery. Fracture patterns show up as lineaments on the imagery. It is extremely important to obtain ground truth because lineaments may be caused by nongeological factors.

Air photointerpretation is perhaps as valuable as a tool in mapping fracture patterns as other types of sensing techniques. Multiple coverage is not generally necessary.

## **RECOMMENDATIONS**

The following action items are recommended for addressing problems identified by this working group:

- That a central planning organization be structured to develop an overall approach for investigating the Chesapeake Bay. This group should incorporate the efforts of all parties involved in the Chesapeake Bay into a single coordinated program.



- That arrangements be made with the U.S. Coast Guard or another appropriate organization to routinely document and monitor episodic events in the Chesapeake Bay using existing remote sensing techniques.
- That remote sensing (low-altitude aircraft) of Bay shorelines be conducted after severe storm events and on an annual basis to monitor shoreline erosion.
- That a complete bathymetric survey of the Chesapeake Bay be scheduled at an early date by the National Ocean Survey, NOAA. Such a survey is needed for delineating the entire Bay's bathymetry within a short timeframe and can be used for a multitude of purposes (e.g., shoal areas, rates of sedimentation, dredging applications, and channel migration).
- That a deep seismic reflection profile be surveyed up the spine of the Bay. Assistance should be sought from the Marine Geology Division of the U.S. Geological Survey for this work. This kind of profile would provide invaluable data on the geometry of freshwater aquifers, depths to basement rocks, and possibly on faulting in basement rock and coastal-plain sediments.



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## POSSIBLE ROLE OF REMOTE SENSING FOR INCREASING PUBLIC AWARENESS OF THE CHESAPEAKE BAY ENVIRONMENT

Thomas D. Wilkerson, Chairperson

Patricia A. Maher, Associate Editor

Gloria Billings

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Jacob I. Trombka

Tom Wisner

"It is up to scientists to bring their expertise to the world of environmental policy and decision-making of concerned citizens and managers. If scientists expect the public to understand and make use of advanced technology in solving complex environmental problems, then they, the technologists, must themselves become involved in, and educate others to, the use, the impacts, and the practicality of their research."\*

### DISCUSSION 1

Professor Adler provided an early impetus toward continuing the work of the Conference. He said, "That part of the public that attended this Conference actually represents a beginning, we hope, of a continued dialog and interaction. We've now become familiar with people from varying disciplines who are interested in the Bay and Bay problems. What we need to do is become involved in joint programs. For example, in the National Aeronautics and Space Administration lunar program, we organized an informal consortium for the sole purpose of pulling information together to get the maximum scientific yield. We took the opportunity to get together at small meetings that were part of a larger one. We've now developed a method of data handling, the production of materials (e.g., color maps) that enable us to establish correlations between series of different techniques that aid us in learning something about lunar evolution and the lunar surface. This kind of cooperative effort would work very well here. Out of this conference should come some means of increased collaboration, cooperation, and exchange of information."†

Information should be compiled on past demonstrations of remote sensing in the region. This is partly underway at the Goddard Space Flight Center. Information gaps on techniques

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\* Breidenbach and Whitman, *Proceedings of the Conference on Environmental Modeling and Simulation*, Environmental Protection Agency, April 19-22, 1976.

† Adler, Session VI Transcript, Conference on the Application of Remote Sensing to the Chesapeake Bay Region, pp. 10-13.

and problem-solving should be pointed out. Existing remote sensing techniques should be demonstrated as an aid in solving those problems. Development of remote sensing techniques should be encouraged in the analytical area, where gaps still exist.

*The working group recommends that a Remote Sensing Task Force be formed to further the knowledge of remote sensing technology and its use in the Chesapeake Bay region.*

## DISCUSSION 2

The need to preserve the Bay and the reasons for its preservation have been cited and studied from particular viewpoints by many groups at numerous meetings and conferences, especially within the last 10 years. At this Conference, the developing technology of Landsat was presented as a potentially valuable tool in Chesapeake Bay management. The geographical overview afforded by Landsat types of imagery has proved to be very effective in stimulating awareness of environmental phenomena. Accomplishments to date suggest that this technique is an effective environmental educator and may evolve into a comprehensive method of surveying land and water environment. Its use has been documented and evaluated both in this area and in other areas of the United States.\*

*The working group recommends that Landsat imagery be recognized as a major initial step in the evolution of remote sensing technological developments that can build awareness of the environment and its changes.*

## DISCUSSION 3

Considerable technical and scientific information was exchanged among the participants at the Conference. Those in the field of remote sensing shared the opportunity to acquaint themselves with new techniques and to ingest meaningful work related to their specialty. Because a wider audience for remote sensing information will stimulate a sense of personal relationship to the Chesapeake Bay system, several ways to extend that information base were suggested:

- Make available to the general public information summaries illustrated with satellite imagery—pictures of the Earth taken from orbit are particularly suitable for museum and library displays.
- Write articles for magazines such as the *National Geographic* and the *Smithsonian*.
- Prepare presentations for the "idea-effective" public, such as citizens groups, congressional staffs, and science advisors.

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\* Sally M. Bay, *Final Report and Recommendations of the National Conference of State Legislatures Task Force on Uses of Satellite Remote Sensing for State Policy Formation*, 1976, and *State Recommendations on Approaches to Landsat Technology Transfer*, 1977, National Conference of State Legislatures.

- Submit appropriate articles and features to inform managers and specialists in related fields. Planners regularly read *Planning or Practicing Planning* and the *Journal of American Institute of Planners*. The American Chemical Society publishes *Environmental Science and Technology*, another possibility for reaching out to specialists on their own turf.

Environmental education has proved to be amenable to various techniques involving "new experiences" or "alternative" experiences, in which exposure to the people in a region, the feel of the outdoor life, and the interplay of the environment, customs, art, poetry, and history convey to the average person more of the importance of grasping the nature of his environment and its problems than is delivered by the sciences alone. In addition to its technical and objective aspects, remote sensing has a place in stimulating man's desire for wider understanding of his environment. Incorporation of the products of this technology into environmental education is expected to contribute materially to the attainment of those educational goals.

*The working group recommends that information on the environmental applications of remote sensing technology be systematically and increasingly shared with the public.*

#### DISCUSSION 4

Because improved public information leads to laws and policies that provide better protection of the environment, two action steps were deemed to be appropriate:

- To gather existing information surveys on public awareness (e.g., "A Resident Opinion Survey About the Chesapeake Bay" that Dr. Shabman\* of the Virginia Polytechnic Institute and State University analyzed and commented on.
- To design a citizens' survey that performs the educational function of enhancing awareness of the Bay as a totality by including questions that address: (1) the awareness of long-range and long-term environmental effects rather than local or immediate concerns, and (2) the environmental applications of remote sensing, (i.e., its usefulness for management and monitoring changes).

*The working group recommends that existing surveys be collected and new surveys be designed to determine and enhance public awareness of the total Chesapeake Bay environment and its manmade changes.*

#### DISCUSSION 5

The Bay is presently managed by many agencies on a piecemeal, particular-interest basis. One Conference theme discussed by the group was the establishment of a single "agency to

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\* Leonard A. Shabman and Peter Ashton, "Citizen Attitudes Toward Management of the Chesapeake Bay," Bulletin 96, Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University, February 1976.

to trust." A focus on one management or coordinating authority would give the public the opportunity to develop an overall view of the regional environment and how it is affected by different influences. Such an agency or commission should compile and coordinate existing inventories and indexes from the many studies relevant to the Bay. As part of its function, this commission should provide assistance to the public in obtaining environmental information, including remote sensing data and technology on the Chesapeake Bay.

*The working group recommends that a coordinating regional institution be established, funded, and legally mandated to develop a management plan for the Chesapeake Bay.*

## CONCLUSION

Remote sensing is an instrumentality that, by its breadth and scope, possesses a unique capability for helping people to perceive the Bay and its environs as an entity, a related and integrated whole. With it, each sector of its many "publics" can be made aware that what each does, in whatever part, affects all of them. We are a part of that public who have, at this Conference, promoted understanding, appreciation, and knowledge of some aspects of remote sensing applications to Bay problems. By sponsoring and participating in the implementation of the recommendations of this working group, we too will reap the benefit.

## REFLECTIONS ON THE REMOTE SENSING WORKSHOP

**Norman H. MacLeod**

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The observations I have in mind concern the problems of "getting them to use our technology to solve their problem." These are the problems of technology transfer. Perhaps these problems can be isolated from the technology applications programs, which have answers seeking questions and, of course, often find them. I think that technology transfer also differs from marketing of new technology. A buyer of technology is deciding to invest—a decision based on a conscious need for the technologies. Technology transfer often begins because the originator of the technology is in many ways a seller looking for a buyer.

Developers of remote sensing technologies form a community—a subset of the scientific and engineering community. Members of that subcommunity who attended this symposium are evidently, perhaps even conspicuously, on a first-name basis. My feeling is that something of a family reunion has been held, because I've enjoyed seeing colleagues with whom I've worked for years and from whom the technology of remote sensing has emerged, especially space applications of this technology. As a group, we speak the same language of spacecraft, sensors, data processing, and applications. We share a methodology or approach to problem solving as a result of our work with space platforms—a systems approach. Although we experience the diversity found in every human community, we can be identified by our language, by our methods, and often by our aspirations; we want our technology to be used.

And the technology is used. During the symposium, we heard several presentations by users in forestry, geology, land use, and fisheries. Most of these uses are still exploratory (that is, the technology-to-users transfer has yet to be completed). I will explore this problem further in a moment.

Another community was here in force—the community of managers of the Bay's resources and, with them, the Bay community itself. The latter was eloquently led by Senator Mathias, our keynote speaker. Senator Mathias spoke of the many interrelated uses of the Bay, the stress that threatens the life of the Bay, and his sense of urgency and love for the Chesapeake Bay. Tom Wisner brought the life of the people of the Bay to us through his beautiful multimedia expression drawn from his life on the Bay. Max Eisenberg brought home to us the meaning of data gathering on the Bay—the task of visiting 2200 stations each month by boat to obtain physical and biological data on the health of the Bay. Milt Moon demonstrated the high technology he practices to meet legal and regulatory requirements of power-plant siting. Our friends from the Corps of Engineers showed us their method of keeping the Bay clear with minimum damage and their means of physically modeling theebb and flow of the

Bay waters. These people form a community whose daily work is on the Bay and those whose lives are daily touched by the Bay. They form a more diverse community, perhaps, than that of the remote sensors, at least in terms of language, because they are engineers, biologists, watermen, homeowners, and boatmen. I have heard a common thread of aspiration—to maintain the health and beauty of the Bay, whether that means open channels for workboats, oysters clean enough for market, geese in the tide marsh, or a harbor tour in Annapolis.

Our communities communicated to our symposium their requirements and their capabilities. However, for all the common talk, we have only begun our communications and our mutual work of applying remote sensing technology to the Bay. I would like to discuss communicating about technology or transferring technology. First, let us take a communications model. A transmitter broadcasts to a receiver through a common medium. In radio or television (TV), we use such systems to effect a message transfer. When one has access to a radio or TV, one has only to be close to a station to receive the signal. But communications is more than a signal or received emanation from a sender. The sender must successfully impose a message on the signal—a message that is comprehensible to the receiving station. McLuhan's aphorism, "the medium is the message" is a compact way of stating not only the communications model, but also that the mode of transmission affects the receiving station. McLuhan also feels that the TV medium is "tribal"—that the message is direct. It forms a community, imprints messages on the members, and closes the community inwardly. We need no training or development to receive TV; it comes from within one community, and is received by that community. I believe that space imagery has some of the TV medium attributes because I have experienced the direct unlearned reception of the imaged message—the content of the space image—by unlettered nomads and peasants in vastly different societies. They have "read" the image immediately, locating their villages, pastures, and problems in the image. What has this to do with our planning for change in the Bay or with the application of remote sensing technology to Bay problems?

I am beginning to realize that speaking across community lines, as we have been trying to do, requires some changes in the technology by each community; in our case, it requires a change or a substantial transformation of the remote sensing technology that we are reaching for and that we want to apply. I hope you will forgive some extended thoughts, but they address a problem that we constantly encounter in remote sensing, in development programs in the third world, and perhaps in all projects in which technology transfer is attempted.

The transformation that I now believe is required is a shift in the context of the technology—the context of remote sensing. Language, objects, and experience form that context. The community of technology origin (our remote sensing community) cannot transfer or apply its technology to an outside community (our Bay management community) until the outside community transforms the technology into its own context. The community of origin must



be the agent to begin change for specific technology transfers. The specific outside community must do all the technology transformation, albeit with the support of the originating community.

In a rural community, change is not accepted until the community has rewoven the warp and woof of daily life to require the change, to name the change, and to experience the change. Max Eisenberg's boat crews will continue to service those stations in the Bay until a new method is accepted, not as something better technically, but as something they have used every day, that they now need to do their job and in which they have confidence to do the job. Obviously, we haven't reached that point of change, even though we have the tools to bring about the change.

I've talked about communities because I believe the obstacles to, and opportunities for, technology transfer are primarily human. We have formed a community within this meeting; we have come together to explore means of using remote sensing to address Bay problems, and we have become agents of change. That is a measure of success. But we are seeking a path to achieve planned change. In other words, having formed a new technology, we seek a means of transforming that technology with the Bay communities so that the Bay communities can use that technology as a matter of course. It is evident that the telling is not enough.

Senator Mathias has worked for several years to bring about a regional commission for the Bay, such as those of the Potomac and Susquehanna River Basin Commissions. There would be \$750,000 to support such a commission. I hope our recommendations will support the formation of a Chesapeake Bay Commission.

My suggestion to the principal investigators and to our chairperson is an evolutionary one. Instead of forming a Remote Sensing Center at this time, I suggest that the people interested in continuing the work of this symposium and in carrying out its recommendations, specifically those of the six panels, form a task force of themselves. Each participant or task-force member would formally notify the task force that his participation is approved by his agency. This means that agency approval would, in fact, be obtained and that the conditions of participation would be an agreement between the agency and the task force. The content of the agreement could be a small amount of release time, the use of specific equipment for specified times, and perhaps a bit of front money cash, but it would be an agreement that the participant can participate in with the blessing of his home institution.

The task force would meet once a month to receive reports, to prepare newsletters and other reports, to assign duties, and to form working groups so that a body of experience and an experienced body can be developed.

Such a task force could conduct a remote sensing survey of the Bay region, bringing the Bay region mosaics up to date, and participating in land-use or sedimentation mapping.



They could assist in site studies, correlating remote sensing data with data gathered by conventional methods. In fact, many activities, including those projects done in part by more than one agency, are candidates for task-force participation and present opportunities for experimental evolution of remote sensing activities on the Bay.

Such an evolutionary process can also lead to the support of a practical nature to Senator Mathias' concerns. We could expect agencies of the federal government (such as the Environmental Protection Agency, the National Aeronautics and Space Administration, the Department of the Interior, the U.S. Geological Survey, and the Department of Defense), state governments of Maryland, Virginia, Pennsylvania, Delaware, and their agencies, and local groups of industry, commerce, and citizens to participate in the task force. The task force could consciously evolve toward formation of a technical subcommission that could provide important experience in attacking the regional and multiple problems of the estuary.

Eventually, the task force would have its own technical resources in addition to access to the resources of participating agencies. But again, the evolutionary path would reduce the required initial funding and the administrative arrangements that can be gained only after time-consuming battle and would minimize the initial staff levels.

Perhaps a first task of the task force would be to set its goals and its approach to meeting those goals and to determine what resources are now available from the participants for planning a beginning toward the agreed-upon goals.

To return to the transformation question, it is important to keep in mind the community nature of technology transfer—the need for the receiving community to be the transforming agent and for the originating community to support the transformation. Within a task force that is conscious of those needs, we could transcend the objective of this symposium, going beyond “planning for change” to changing the mode of mending the Bay and the means of minding the Bay.

## RESOURCE CONTRIBUTIONS

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## **NCSL TASK FORCE FINDINGS ON FEASIBLE STATE USES OF LANDSAT**

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### **ABSTRACT**

The National Conference of State Legislatures (NCSL) appointed a Task Force to review state applications and limitations of the National Aeronautics and Space Administration's (NASA's) current and proposed Landsat capabilities. Existing Landsat applications performed by state data users were presented to the Task Force through a survey of 136 state agencies now using satellite data. Formal testimonies were also presented to the Task Force by a number of state program managers. It was found that current uses of the data involve state programs such as land-use planning, wetlands management, coastal zone management, transportation planning, forestry management, etc. This paper summarizes the current and potential uses of Landsat data as perceived by the NCSL Legislative Task Force after reviewing the technology, data needs for state natural resources programs, and state capabilities for using satellite technology.

As a service organization for the nation's state legislators and their staffs, NCSL has three primary objectives:

- To improve the quality and effectiveness of state legislatures
- To ensure that states have a strong, cohesive voice in the federal decision-making process
- To foster interstate communications and cooperation

### **TASK FORCE FINDINGS**

In May 1976, NCSL established a Task Force to review the feasibility of state interest in the Landsat Program. To determine this feasibility, the states' needs for Earth resources data and the capabilities of existing and proposed satellites were considered. The Task Force, comprised of legislators, legislative staff, and a technical subcommittee of state program managers, surveyed the opinions of 136 state agencies involved in using Landsat data. It

became apparent that there are many potential uses in the states for satellite data, particularly with the technical improvements promised by NASA.

The Council of State Governments reviewed state and federal legislation that mandates the state programs requiring Earth resources information for the Task Force. The following key state programs emerged as having high demand for such data:

- Land-use planning
- Wetlands management
- Coastal-zone management
- Flood-plain management
- Water-quality management
- Agriculture
- Fish and wildlife
- Transportation planning
- Forestry management
- Water resources planning
- Land reclamation
- Air-quality management
- Solid-waste management
- Environmental impact statements

The predominant information needs of these programs were analyzed to determine the potential of the proposed Landsat-D for satisfying those needs. Table 1 summarizes the findings by type of program.

The Task Force concluded that Congress, as well as the states, should actively support continuation of the Landsat Program with its proposed improvements (e.g., 30-m resolution and better vegetation analysis capabilities). They unanimously agreed that Landsat data can potentially fulfill many state information needs. However, implementation of the highly technical Landsat capabilities as an information tool requires more than a satisfactory performance by the satellite. It became obvious to the Task Force that the real difficulties in the program are in building the states' capabilities for employing the satellite technology.

Table 1  
Satellite-Based Data Applicability for State Program Activities\*

State Program	Legislative Origin	Program Functions	Landsat-D Potential	Landsat Data Now Used	Examples of Agencies Using
Land-Use Planning	HUD 701: State Legislation (e.g., Vermont Act 250, Florida Land and Water Conservation Act, and Oregon Land Conservation and Development Act)	<p>Policy development</p> <p>Plan preparation</p> <p>Land-use regulation</p>	<p>Yes</p> <p>Yes</p> <p>Yes</p>	<p>Yes</p> <p>Yes</p> <p>Yes</p>	<p>Oregon Department of Land Conservation and Development</p> <p>Oregon Department of Transportation</p> <p>Oregon State Forestry Department</p> <p>Oregon Department of Environmental Quality</p> <p>Southeast Missouri Regional Planning Agency</p> <p>University of Missouri Agricultural Extension Service</p> <p>Missouri Office of the Assistant State Soil Scientist</p> <p>Hawaii State Planning Department</p> <p>Washington Office of Community Development</p> <p>Washington Department of Natural Resources</p> <p>New York State Economic Development Board</p> <p>Maryland Department of State Planning</p> <p>Southwestern Illinois Metropolitan and Regional Planning Commission</p> <p>South Dakota State Planning Department</p> <p>Indiana State Planning Service</p> <p>Ohio Department of Natural Resources</p> <p>Louisiana State Planning Department</p> <p>Idaho Division of Budget, Policy Planning and Coordination</p> <p>Idaho Department of Water Resources</p> <p>Idaho Department of Lands</p> <p>Ada Council of Governments (Idaho)</p> <p>New Mexico State Planning Office</p> <p>Georgia Department of Natural Resources and other Georgia agencies</p>

\* Final Report of the NCSL Task Force on Satellite Remote Sensing.

Table 1 (Continued)\*

State Program	Legislative Origin	Program Functions	Landsat-D Potential	Landsat Data Now Used	Examples of Agencies Using
					Arizona Resources Information System Ohio-Kentucky-Indiana Regional Council Los Angeles Department of City Planning Federation of Rocky Mountain States New Mexico Bureau of Mines Iowa Geological Survey Illinois State Geological Survey Department of Geology, University of Arkansas (for predicting landslide-prone areas in highway construction) Minneapolis/St. Paul Metropolitan Council (limited experiment) Wisconsin Bureau of Planning and Budget Minnesota State Planning Agency Triangle J Council of Governments Jefferson-Port Townsend Regional Council (Washington) Multnomah County Department of Environmental Services (Oregon) Thurston Regional Planning Council (Washington)
Wetland Management	State Legislation (e.g., Maryland Wetlands Act of 1970, amended 1974, and Washington Shoreline Management Act of 1971)	Wetland identification  Development permit review Management enforcement	Yes  No Yes	Limited  No Limited	Alabama Geological Survey Texas General Land Office Virginia State Water Board Tennessee State Planning Office (requires site visit)
Coastal Zone Management	Federal Coastal Zone Management Act and State Legislation (e.g., California Coastal Zone Conservation Act and North Carolina Coastal Zone Management Act)	Plan preparation  Management enforcement	Yes (for a limited number of data elements) Yes	Yes  Yes	New York State Economic Development Board Wisconsin Bureau of Planning and Budget Alabama Geological Survey

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Table 1 (Continued)\*

State Program	Legislative Origin	Program Functions	Landsat-D Potential	Landsat Data Now Used	Examples of Agencies Using
Forestry Management	State Legislation (e.g., Mississippi Forest Harvesting Act and Oregon Forest Practices Act)	Harvest management Reforestation Disease/pest control Erosion protection Land capacity	Yes N/A Yes	Yes N/A Limited	Minnesota State Planning Agency Washington Department of Natural Resources Oregon State Forestry Department Idaho Department of Lands
Fish and Wildlife Management	State Legislation	Regulation of resource Extraction Habitat assessment	Yes Limited	Limited Limited	Washington State Department of Game Oregon Department of Fish and Wildlife
Air-Quality Management	Federal Clean Air Act	Air-quality control	Limited	No	
Solid-Waste Management	State Legislation	Disposal facility siting	Limited	Limited	
Environmental Impact Statements	National Environmental Policy Act State Legislation (e.g., Colorado Environmental Policy Act and Montana Environmental Policy Act)	Disposal monitoring  Electromaging system preparation	Limited	Limited	
Transportation	Federal Legislation	Corridor selection Facility planning and construction Location of materials sources	Yes Yes Yes	Limited Limited Limited	Idaho Transportation Department Division of Highways
Water-Resources Management	Federal Water Resources Planning Act and State Legislation	Surface-water supply development Ground-water supply development Monitoring water systems	Limited No Limited	Limited No Limited	Minnesota State Planning Agency Idaho Department of Health and Welfare

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Table 1 (Concluded)\*

State Program	Legislative Origin	Program Functions	Landsat-D Potential	Landsat Data Now Used	Examples of Agencies Using
Land Reclamation	State Legislation (e.g., New York State Mined Land Reclamation Act and Wisconsin Metallic Mining Reclamation Act)	Surface-mined areas identification	Yes	Yes	Alabama Geological Survey Kentucky Department of Natural Resources and Environmental Protection North Dakota State Geological Survey
		Certifying reclamation activities	No	No	
		Monitoring reclamation activities	Limited	Limited	
Flood-Plain Management	Federal Legislation (i.e., National Flood Insurance Act of 1968 and Flood Disaster Protection Act of 1973) State Legislation	Define flood-plain Land-use regulation	Limited Yes	Limited Yes	Alabama Geological Survey
Water-Quality Management	Federal Water Pollution Control Act and Amendments	208, 303(e) Planning	Yes	Yes	OKI Regional Council of Governments Triangle J Council of Governments
Agriculture	State Legislation	Production monitoring	Yes	Yes	University of Missouri Agricultural Extension Service Idaho Department of Water Resources Oregon Water Resources Department
		Crop advice	No	No	
		Monitor grassland and rangeland	Yes	Yes	

\*Final Report of the NCSL Task Force on Satellite Remote Sensing.

Approval and encouragement for continuing the Landsat Program was voiced at NCSL's Annual Meeting in Kansas City in August 1976. The NCSL membership approved a resolution urging congressional support for the Landsat Follow-On Program as follows:

WHEREAS, the National Conference of State Legislatures' Task Force on Satellite Remote Sensing for State Policy Formulation has conducted a six-month, intensive review of State uses and potential uses of remotely sensed information; and

WHEREAS, the Task Force has found innumerable State activities about which more informed decisions could be made with the systematic availability of remotely sensed information; and

WHEREAS, these activities have included agriculture, forestry, natural resources conservation and development, minerals extraction and reclamation, energy conservation, air and water pollution detection and many others; and

WHEREAS, much recent Federal legislation, such as the Coastal Zone Management Act of 1972, has levied substantive requirements upon the States that can best be fulfilled by new and expanded information; and

WHEREAS, the National Aeronautics and Space Administration's Landsat Program has provided data on a developmental basis that has contributed to the States' ability to meet their expanded responsibilities under many Federal programs, and

WHEREAS, the National Aeronautics and Space Administration has proposed a Landsat Follow-On Program to operationalize the data collection process of the Landsat Satellites; and

WHEREAS, this proposed Landsat Follow-On Program will provide for improved data collection capabilities as well as assure continuance of the current process; and

WHEREAS, the National Conference of State Legislatures' Task Force on Satellite Remote Sensing has found numerous State agencies successfully using this new tool experimentally but reluctant to make long-term commitments because of the uncertainty of the future operational availability of data; and

WHEREAS, the National Conference of State Legislatures' Task Force on Satellite Remote Sensing has unanimously approved a motion urging Congressional support for approval of the Landsat Follow-On Program as well as urging active State support of that Program; therefore

LET IT HEREBY BE RESOLVED, that the National Conference of State Legislatures urges Congress to assure the continuance of the satellite-based natural resources information collection by approval of the Landsat Follow-On Program.

Sponsored by Delegate J. Hugh Nichols, Maryland (for the Task Force)

Co-Sponsored by Senator James A. Mack, Arizona and Robert Testa, California.

### **SOME STATE APPROACHES TO THE USE OF SATELLITE DATA**

Most states have taken a relatively cautious approach to the new satellite technology until assurance could be given for continuing the Landsat Program at the federal level. Generally, states have preferred to attempt special experimental projects, usually for special "high data demand" program needs such as those for Section 208 of the Federal Pollution Control Act and Amendments, rather than attempting immediate operational use of the technology. Although many states have used federal grants for such projects, some states have used state funds and believe the money was well spent even if the program may not continue.

#### **Texas**

In Texas, the establishment of the Texas Natural Resources Information System (TNRIS) in 1973 stimulated interest in more effective data-collection efforts. The system provides state, federal, regional, local, and private entities with all available, cost-efficient natural-resource information. The demands of the agencies are constantly changing and expanding in response to many federal and state programs, such as water-resource planning, coastal-zone management, energy-conservation programs, and land-use planning.

In providing an efficient, centralized information source, the TNRIS has had to cope with the rapidly expanding requirements of its participants. Thus, satellite remote sensing has been used by the TNRIS and its participating agencies as an additional, effective data-collection tool that has proven useful for:

- Coastal-zone management
- Natural-resource inventories
- Land-use change identification.

Therefore, Landsat is well accepted as an aid to providing an information base for program implementation in Texas.

#### **Georgia**

The Georgia Department of Natural Resources recently completed a demonstration land-use inventory project based on Landsat data with the aid of NASA's Earth Resources Laboratory in Slidell, Mississippi. The resulting map product was so well-received that additional Georgia agencies have contributed funds for completing a Landsat-based inventory of the entire state. This need has been largely spurred by the demands of Section 208 of the Federal Water Pollution Control Act. Field data is now being collected by the professional staffs of participating agencies. It is hoped that all necessary statistical training data will be available for use by August 1. Georeferencing and other computer tasks are being performed by the Georgia Institute of Technology.

### **Pacific Northwest—Washington, Oregon, and Idaho**

In 1974, the Pacific Northwest Regional Commission initiated a demonstration project to assess the feasibility of Landsat as a tool for land-cover information gathering. Thirty-five resource management agencies from the three states and technical personnel from NASA and U.S. Geological Survey (USGS) have worked closely in this project. By late 1975, a set of base maps at the scale of 1:250,000, 1:500,000, and 1:1,000,000 were produced for the three states. Overlays for these maps include:

- Level 1 land use (based on USGS Circular 671)
- Soil information
- Federal, state, private ownership boundaries
- Drainage basins
- Energy-related information

A number of local problem-oriented efforts with Landsat are now underway. A few of these on-going activities are as follows:

#### ***Snake River Irrigated Lands Inventory (Idaho)***

A multistage analysis is being used by the Idaho Department of Water Resources to identify irrigated lands and the resulting water demand. This information will be used to monitor irrigation and ground-water diversion projects, as well as water-rights violations. Conventional approaches to data collection using field surveys are being curtailed because of high costs. The agency believes its effectiveness will be diminished without tools such as Landsat to provide better data-collection capabilities at relatively lower costs.

#### ***Oregon Reservoir Volume Determination***

Conventional approaches to collecting reservoir-volume estimates is labor intensive and inaccurate. In fact, the total number of reservoirs in the state is only an approximation. The Oregon Department of Water Resources is therefore attempting to use Landsat to effectively perform this task in addition to their irrigated lands survey.

#### ***Western Washington Forest Inventory***

In response to the State Forest Practices Act and the State Shoreline Management Act, the Washington Department of Natural Resources has begun to turn its attention to *all* forested areas, rather than only those that are state-owned. Although standard methods of air photography data are acceptable, it is hoped that Landsat will provide timely, cost-effective information for surveying the more extensive areas. It is estimated that the inventory could be completed through conventional means at a cost of \$2.0 million over a period of several

years. With Landsat, the cost estimates are under \$200,000 with a completion time of about 1 year.

New tools for collecting land-cover data and for developing resource-management information are sought by the resource management agencies of the Pacific Northwest for two basic reasons:

- Data collection for the new and on-going functions by conventional approaches is heavily plagued by rising costs.
- The data requirements for implementing many of the new programs are "too great" for conventional methods in terms of area coverage required, time schedules, costs, etc.

The Pacific Northwest Regional Commission (PNRC) has officially taken the position that Landsat systems will be used for those urgent data demands that are beyond the scope of conventional data collection methods.

### **North Dakota**

The North Dakota Regional Environmental Assessment Program (REAP) was established by the North Dakota Legislative Assembly in 1975. This Program is the result of legislative concern for a thorough, well-maintained data base as a tool for effective decision-making. It is to provide a system for environmental, socioeconomic, and sociological data analysis and to conduct integrated impact assessment of potential developments in the state. To achieve its goals, a capability for statewide land-cover analysis was given high priority. Landsat data was chosen as the best approach for achieving a land-cover inventory. The Bendix Corporation contracted to provide this service for REAP. Resulting products will include a 1:500,000 statewide land-cover map depicting ten categories of land cover with accompanying computer tabulations, plus 1:126,720 scale maps for each of the state's 53 counties. In turn, these data will be integrated with other information to provide legislators and other state decision-makers with a basis for making decisions. For example, one of the priority goals is to determine the potential impacts of large-scale coal developments in southwestern North Dakota.

Other state legislatures have also begun to take an interest in data availability and the role of Landsat as a data tool. In New York State, there has been legislative interest in data availability for implementing recently approved programs, such as one requiring state environmental-impact assessments. California legislators have also been reviewing Landsat capabilities. Their concern is for accurate information relative to proposed bills on state agricultural activities and water-resource management policies.

### **NEW AGE OF LANDSAT AS A STATE DATA TOOL**

Pressed by the demands of more effective decision-making regarding our natural resources and realistic implementation of the many resulting federal and state programs, states are increasingly looking to satellite technology as a timely, cost-effective data gathering tool.

Indeed, some program managers have already insisted that without Landsat some of the new programs cannot possibly be implemented. However, it must be remembered that Landsat cannot in itself provide everything a state needs to know about natural resources. Landsat should not be expected to provide detailed, site-specific analysis. Its resolution capabilities prevent that type of use. However, as a tool for general recurring information over a large area, it is extremely effective. In some cases, agencies have been disappointed in satellite data because expectations were incorrectly focused on extreme detail. It must be remembered that Landsat is but one tool in achieving an effective analysis.

In addition, many times it all looks so easy. One cannot simply push a button and acquire a multicolor, 15-category land-use map of the state, highlighting all recent developments in the coastal zone. There are many variables to consider in terms of image interpretation versus digital-computer methods, most effective equipment for producing the desired product, which software package to use, and even whether to develop the capabilities for in-house production or to contract it out to a firm. If the private contractor option is chosen, available choices of firms or universities must be discovered, and an evaluation of their relative capabilities must be made. Otherwise, the result could be wasted effort and expense on a useless product for the immediate need.

Obviously, the transfer of a new technology is not an easy process. NCSL urges states to establish effective in-state communications processes for a coordinated state approach. Awareness of the alternative approaches and their potentials and pitfalls is essential to the transfer process. Communications links between states, as well as with the appropriate federal agencies, is therefore essential. NCSL is one mechanism for assisting states in this communications aspect. NASA is in the process of focusing user assistance activities through three centers: Goddard Space Flight Center, Greenbelt, Maryland; Earth Resources Laboratory, Slidell, Mississippi; and Ames Research Center, Moffett Field, California. When fully established, these centers should be able to effectively assist the states with their needs for information, personnel training, and technical advice.

It is NCSL's perception that Landsat technology offers tremendous potential for assisting states with their data requirements. The federal government should carry through with making it a reachable, operational program for the states. It will then be each state's responsibility to make a serious commitment to its utilization.

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## **PROGRESS TOWARD A CIRCULATION ATLAS FOR APPLICATION TO COASTAL WATER SITING PROBLEMS**

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### **ABSTRACT**

Circulation data needed to resolve coastal siting problems can be assembled from historical hydrographic and remote sensing studies in the form of a Circulation Atlas. Empirical data are used instead of numerical model simulations to achieve fine resolution and to include fronts and convergence zones. Eulerian and Lagrangian data are collated, transformed, and combined into trajectory maps and current vector maps as a function of tidal phase and wind vector. Initial Atlas development is centered on the Elizabeth River, Hampton Roads, Virginia.

### **INTRODUCTION**

The siting of coastal facilities to utilize water resources usually requires assessment of local circulation. Circulation studies are needed with respect to siting sewage and industrial outfalls, municipal water supply intakes, oil tanker and pipeline routes, tanker loading facilities, electric power generating stations, and harbor construction or modification projects. These needs can be met by either direct field study of circulation at the sites in question or use of numerical or physical hydrodynamic models. However, limitations in these approaches have been recognized (see, for example, Tracor, Inc., 1971), and they provide the stimulus for a continuing search for new or improved methods.

Historically, field studies of circulation at sites of interest have been time consuming and expensive. Because of the high expense, circulation study for a coastal facility has nearly always been limited to a single site. Remote sensing cuts the time and expense of circulation studies and permits simultaneous study of alternate sites (see, for example, Munday, Welch, and Gordon, 1977).

Despite high expense, field studies are sometimes repeated without full utilization of earlier data. Studies of circulation tend to be left unrelated because purposes and locales vary from



one study to the next, and it is not a superficial matter to decide whether earlier studies will satisfy a new need. Also, the effort to integrate a number of studies is beyond the scope of an individual siting study.

Piecemeal studies of circulation in a particular locale could nevertheless be integrated. A special effort could be undertaken to evaluate earlier circulation studies and uncover data gaps in terms of spatial, tidal, and wind-vector dimensions. The data sources would include hydrographic studies, dye studies, and aerial and satellite remote sensing studies. This special effort would be the prelude to all future study of local circulation in that it would define which new studies would have to be performed to complete a sufficiently detailed picture of local circulation. It would introduce a uniform format for data emanating from studies using different methods. It would permit the setting of confidence limits in knowledge already classified, and it would establish a basis for future study design by making clear what confidence limits are usual and appropriate. The results might aid in the analysis of different methods of circulation study, with respect to their cost-effectiveness.

A very useful product of such an effort would be a Circulation Atlas. Conceptually, the Circulation Atlas is a readable compendium of circulation charts for different wind and tide combinations. The Atlas contains examples of the full range of empirically encountered flow-field patterns in a single easily accessed document. It is oriented toward users in consulting engineering firms and local governmental agencies.

### CONCEPT DEVELOPMENT

The Atlas is envisioned as providing a first look at current patterns and flow-field trajectories. Available for use in the same manner as nautical charts and topographic maps, it would constitute a reference for users such as Coast Guard marine-safety offices, local governmental agencies, commercial fishermen, and engineering consulting firms that are conducting siting studies or preparing environmental impact statements. It would provide a basis for making broad preliminary decisions with respect to siting questions.

The Atlas would be limited to portraying representative examples of the conditions that might prevail, in contrast to numerical and physical models that are used for simulation and quantitative prediction for new sets of conditions. For applications requiring quantitative prediction of pollutant dispersion or the effects of shoreline modification, simulations would generally be necessary, and the data presented (or other data) would have to be manipulated by means of models.

Various components and formats could be employed. The principal component would be surface and/or depth-averaged current vector flow-field maps as a function of hourly or quadrature tidal phase and wind velocity (graded into classes). A complementary component could be trajectory maps for various release points of interest. Guidelines might be included for making gross estimates of the effects of other conditions (for example, other wind conditions).

The main objective in developing the Atlas is to permit better siting decisions on the basis of a maximum understanding of current dynamics and circulation. The availability of an Atlas will improve the use of historical circulation data and reduce the need for additional data to solve new siting questions. It will improve the understanding of estuarine fronts and convergence zones as related to small-area siting questions. Finally, it will facilitate the development of standard methods for integrating and communicating circulation data for siting decisions.

### USING A NUMERICAL MODEL TO PRODUCE A CIRCULATION ATLAS

A numerical hydrodynamical model can be used to generate a current-vector flow field. The extensive literature on numerical models of tidal rivers, estuaries, and coastal waters (see Tracor, Inc., 1971; Gordon and Spaulding, 1974; Caponi, 1974; and Elliott, 1976) contains numerous examples of flow fields as a function of tidal phase. These may be suitably annotated and published as a Circulation Atlas; for an example showing the hourly tidal-current flow field for Narragansett Bay, Rhode Island, see Spaulding and Swanson (1974).

Numerical models are widely used and are satisfactory for selected circumstances. Their principal limitation lies in their relatively coarse spatial resolution, a limitation that arises from the rapid growth in computer storage requirements and computational time as the number of spatial resolution elements increases. For a two-dimensional model (vertically averaged), a decrease in length of a resolution cell to one-half the original value increases the computational time by a factor of 8. The number of resolution cells in a time-dependent two-dimensional model for Hampton Roads, developed at Virginia Institute for Marine Science (VIMS) for pollutant predictions, is several hundred, with a horizontal spatial resolution of approximately 1.2 km (Kuo, private communication, 1977).

Three-dimensional models for estuarine circulation have now been published, but these are even more restrictive in terms of spatial resolution. Caponi (1974) applied a three-dimensional model to the Chesapeake Bay, using up to four vertical resolution elements, but only 68 horizontal cells for the entire Bay. A simulation extending for 10.55 days required 80 minutes of computational time on the Univac 1108 at the Computer Science Center, University of Maryland. Elliott (1976) has remarked that a further disadvantage of three dimensional models is the practical difficulty of collecting enough high quality field data to adjust and verify them.

Because of their coarse spatial resolution, numerical models are not always suitable for small-area siting studies. A recent siting study in Hampton Roads (Munday, Welch, and Gordon, 1977) involved an area of less than 10 km<sup>2</sup>; to apply a fine-grid model to this small area would have required either an excessive number of cells in order to reach shoreline in all directions, appropriate treatment by the model of open boundaries on three sides, or acceptance of excessively coarse spatial resolution. A field study would also have been required to obtain the needed calibration data for the model. In view of these considerations, the decision was made to study the area by a remote sensing method because remote sensing is quicker and cheaper.

Another consideration for small-area studies is that of fronts and convergence zones. These are not resolved by the coarse resolution of typical hydrographic field studies, and numerical models would blur them via continuity assumptions even if field studies resolved them. If models could accommodate fronts, a three-dimensional time-dependent model would be needed to investigate their effects on pollutant transport. Fronts are noteworthy in the circulation of the Hampton Roads area and the lower York River, and they are probably important in other areas as well. The significance of such discontinuities is that at times they may be as important for pollutant dispersal as turbulent diffusion and advection processes; consequently, the failure to account for them might lead to erroneous dispersion estimates.

For example, the movement of a potentially significant front at the mouth of the Elizabeth River, Hampton Roads, has now been documented by remote sensing studies involving dye-emitting Lagrangian drifters. The front appears in late ebb at the northeast tip of the Craney Island dredge spoil-disposal area and during the change to flood, moves so as to constrict the Elizabeth River ebb flow in the manner of a choke valve (figure 1). The front appears at the same location regularly with the tidal cycle. Although it had been seen before in several National Aeronautics and Space Administration (NASA) images of Hampton Roads (figure 2), its movement and phasing in the tidal cycle were not understood before the recent drifter studies. The usual hydrographic studies and numerical modeling would not have revealed and delineated this front, but remote sensing has enhanced it. The effect it has on Elizabeth River flushing can now be investigated.

It is doubtful that the limitations of models involving coarse spatial resolution and blurring of fronts will be corrected easily or quickly. For this reason, numerical models will tend to be applied to wide-area problems with bounded water-body configurations, in which the fine details of circulation are not considered important.

#### **DIRECT USE OF FIELD DATA TO PRODUCE A CIRCULATION ATLAS**

For bodies of water with significant pollution problems stemming from moderately dense population and coastal facilities, the interest in siting questions will have resulted in a number of circulation studies by direct field study. These will consist of hydrographic studies (possibly performed to collect data for numerical or physical models), dye studies involving batch dye releases and boat-borne fluorometry, and remote sensing studies involving tracking of Lagrangian drifters or delineation of turbidity patterns. All of these produce data that could be assembled into a Circulation Atlas.

One advantage of using field data instead of simulation data produced by models is that the data are empirical and need no verification. Another is that fine-scale circulation details such as fronts can be included, particularly when the data collection involves aerial imagery. Some disadvantages are that the data may not encompass all the wind and tidal current combinations of interest, the spatial coverage will not be uniform, and the data will vary in type and format.

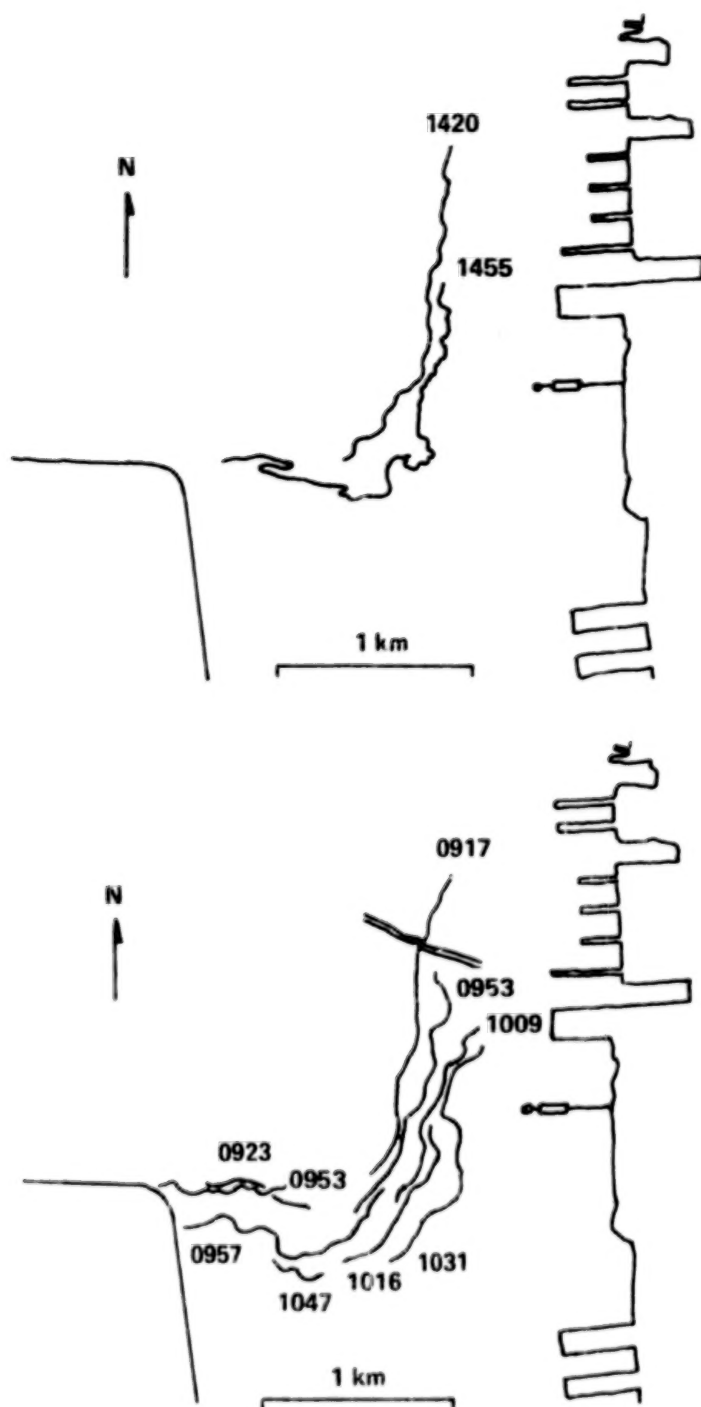


Figure 1. Cross-channel movement of front on Elizabeth River: upper, February 2, 1977; lower, February 10, 1977.



Figure 2. Early flood-tide front on Elizabeth River between Craney Island dredge spoil-disposal area and Norfolk naval facilities (negative panchromatic copy of 2443 color infrared image, NASA Mission 187, October 12, 1971, original scale 1:49,000).

### ANALYSIS OF DATA COVERAGE

The first task is to collect sets of data from earlier studies. For initial development of the Atlas concept, our effort is being centered on circulation in the Elizabeth River. This test area is a relatively small river basin (13 by 3 km) with several river branches. Although it is heavily polluted, it has not been the site of many circulation studies. The paucity of circulation data and its small area make it suitable for developing prototype methods. For the Elizabeth River, the available circulation data consist of Lagrangian data from remote sensing studies (Fang, Welch, and Gordon, 1975; for water-quality data, see Neilson, 1975). These data have been put into computer-compatible format for analyzing the spatial density of coverage and for manipulating to produce Atlas components.

A preliminary notion of the extent of data coverage can be obtained from an experiment condition array (Fang, Welch, and Gordon, 1975), as shown in figure 3, in which rows represent wind direction and columns represent tidal phase. A numerical entry in the array represents the number of experiments performed in the given condition.

		Wind-Speed 0 to 5/5+ m/s (0 to 10/10+ knots)			
W i n d  D i r e c t i o n s	NE	1/0	0/3	0/3	1/2
	SE				
	SW	0/1	1/2	0/1	1/0
	NW	0/1	1/2		1/0
		High	Mid	Low	Mid
		Tidal Phase			

Figure 3. Condition array for Lagrangian drifter experiments on the Elizabeth River (tide reference is Sewells Point).

For more detailed density analysis, the data have been computer-sorted into horizontal resolution cells the length of whose sides is set by an input constant. This length for the Elizabeth River basin has been set at 250 m. The data have been further sorted by wind speed and divided into speed classes. The speed classes have initially been chosen to be 0 to 2.5 m/s (0 to 5 knots), 2.5 to 7.5 m/s (5 to 15 knots), and greater than 7.5 m/s (15 knots). The results of a simultaneous sorting by space and wind speed have been mapped to show the density of coverage of available data. An example of such a map for the southern half of the basin is shown in figure 4.



Wind-Speed Class 2.5 to 7.5 m/s (5 to 15 knots)

Number of Buoys with Average Positions Outside Grid is Eight.

Index Numbers of Buoys Outside Grid

UTM Coordinates

		Easting															
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		7	7	7	8	8	8	8	8	8	8	8	8	8	8	8	8
		9	9	9	0	0	0	0	1	1	1	1	2	2	2	2	2
		2	5	7	0	2	5	7	0	2	5	7	0	2	5	7	7
		5	0	5	0	5	0	5	0	5	0	5	0	5	0	5	5
N o r t h i n g	408375	.	.	.	*	*	*	1	*	1	1	*	1	*	*	*	.
	408350	.	.	.	.	.	.	1	*	2	1	*	*	*	*	*	.
	408325	.	.	.	.	.	.	*	1	1	*	*	*	*	*	*	.
	408300	*	*	.	.	.	.	*	2	*	1	*	*	*	*	*	.
	408275	*	*	*	*	.	.	1	1	*	1	*	*	*	*	*	.
	408250	.	.	*	*	*	*	1	5	5	*	*	*	*	.	.	.
	408225	.	.	1	1	2	1	8	3	*	*	*	*	.	.	.	.
	408200	.	.	1	3	12	11	5	3	*	*	*	.	.	.	.	.
	408175	.	.	*	2	15	5	1	1	*	*	*	.	.	.	.	.
	408150	.	.	*	*	3	2	2	1	*	*	.	.	.	.	.	.
	408125	.	.	.	*	2	13	9	2	*	*	*	.	.	.	.	.
	408100	.	.	.	*	1	5	11	1	*	*	*	*	*	.	.	.
	408075	.	.	.	*	1	1	3	4	*	1	*	*	*	*	.	.
	408050	.	.	.	.	1	1	1	1	1	1	*	*	*	*	*	.
	408025	.	.	.	.	.	1	*	*	1	1	*	1	*	*	*	*
		.	.	.	.	.	*	1	*	*	*	*	1	*	*	*	*

Figure 4. Spatial density of drifter trajectories for Elizabeth River.

It will be necessary to further subdivide the data by tidal phase and wind direction. The initial choice is for quadrature tidal phases and four wind directions. These divisions of tidal phase and wind direction, along with three wind-speed classes, will result in 48 combinations. Obviously, a large amount of field data is required to fill all spatial cells with data for this number of combinations.

An inspection of the condition array and the density maps reveals the extent of data coverage. Data gaps are made obvious, and experiments can be planned to fill these gaps.

### DATA-SET COLLATION

The available data sets consist in general of Eulerian and Lagrangian data collected by different techniques and under various environmental conditions. These data sets must be transformed into a common format and arranged in appropriate order for further manipulation.

For production of current-vector flow-field maps, either the Lagrangian data must be transformed into pseudo-Eulerian data, or the Eulerian data must be transformed into pseudo-Lagrangian data. Although the map that is later produced may be interpreted loosely as consisting of either current vectors or short Lagrangian trajectories, the careful map reader will note the difference. Strictly speaking, for a current-vector flow-field map, those data that must be transformed are the Lagrangian data.

The transformation of Lagrangian data can be accomplished by assigning the average time to the trajectory midpoint, and the current vector can be formed from the distance vector divided by the time interval. Note that this current vector is a measure of the smallest possible speed because it assumes straight-line travel between the points of measurement. Speeds in current fields with vorticity will be undervalued. Note also that the longer the time interval and the longer the trajectory, the less confidence can be attached to the vector assignment, to the trajectory midpoint, and to the average time. Finally, the transformation may result in loss of interesting end-point information. If long trajectories are transformed that stretch over more than one spatial resolution cell, or temporal interval, an analysis of data coverage may leave the false impression that the coverage is sparse. In effect, the transformation will have collapsed a long trajectory and time interval into a point vector, and expanded the spatial resolution and time interval that should henceforth be attached to that point vector.

The transformation of Eulerian data can be accomplished by creating a short Lagrangian trajectory with beginning and end spatial coordinates and times calculated from the measured current vector and centered on its time and location. The new times and coordinates should keep the created trajectory within the chosen spatial resolution and time interval.

Given the possible importance of fronts and convergence zones, these should be incorporated into the data archive with rather complete detail. The obvious method is to digitize their locations with fine spatial and temporal resolution. The resulting data are not expected to increase the data storage requirements by any significant amount.



Each data set must be annotated with header data, including date, wind velocity versus time, and tide data for an appropriate control station.

## DATA SYNTHESIS

The last task before preparing Atlas products is the synthesis of transformed and collated data. The data must be temporally and spatially interpolated to conform to the desired temporal and spatial resolution. If voluminous, data must be averaged.

### Synthesis of Lagrangian Data for Trajectory Maps

One problem with Lagrangian data is that coordinate measurement times will not generally coincide with the times and time intervals that are chosen for map products with reference to tidal control stations. The simple solution is to linearly interpolate coordinates using the measurement data and the desired time. With linear interpolation, the new x-coordinate is

$$x' = x_1 + (x_2 - x_1) \times (t' - t_1)/(t_2 - t_1)$$

where  $t'$  is the desired time, and  $x_1$  and  $t_1$  are the measurement data. A more time-consuming procedure is to fit  $x$  versus  $t$  with a polynomial equation, and insert  $t'$  to obtain the desired  $x'$ . This procedure would smooth obvious irregularities in the Lagrangian trajectory, which might be presumed to be caused by noise or frontal shear. However, there does not appear to be any meaningful advantage in using more complicated procedures, despite their theoretical foundation and possibly higher accuracy, when the Atlas is to be constructed from empirical data and oriented to lay users. Complicated procedures would produce the undesirable result of substantially increasing the computational processing time.

Lagrangian data could also be extrapolated beyond the measurement times as long as the extrapolation time was short. For small-basin tidal currents, points might be extrapolated as long as 15 minutes in the absence of nearby fronts.

Interpolated Lagrangian data from different experiments that become sorted into the same tidal and wind velocity class would then be plotted. A large number of trajectories bunched in a small region might necessitate the use of an averaging procedure and the plotting of the result as an average trajectory.

### Synthesis of Lagrangian Data for Current-Vector Maps

To transform the data into pseudo-Eulerian current vectors at the desired times,  $t'$ , the data can be interpolated to  $t' + dt/2$  (where  $dt$  is an appropriate time interval) and then converted to vectors centered at times,  $t'$ . After wind and tidal sorting, all data at  $t'$  could be plotted, or data in each spatial resolution cell could be averaged and the averages plotted.

For spatial interpolation to fill in areas of no coverage, the Lagrangian data could be transformed by objective analysis methods (see Yeske, Scarpace, and Green, 1975) into velocity vectors for points on a square grid.

### **Synthesis of Eulerian Data for Current-Vector Maps**

The problem with Eulerian data is that current measurement may be either point-in-time data or temporal averages. The associated times will not generally coincide with times chosen for map products. The simple solution for point-in-time data is to linearly interpolate both directions and speeds to the desired times. A more complicated procedure would be to use a tide curve for curvilinear interpolation. For time-averaged current data, no temporal interpolation is necessary because the time-averaging intervals will cover the desired times,  $t$ .

If Eulerian data provide sparse or spotty spatial coverage, it may be desired to fill in areas of no coverage. The simple solution is linear interpolation between successive pairs of points. An alternative, employed by Munday, Harrison, and MacIntyre (1970) in an oil-slick trajectory model, is inverse  $r$ -squared weighting of nearby current meter stations within a cutoff distance. Another alternative is to interpolate the data into a regular grid pattern using objective analysis methods. A procedure for velocity-field interpolation based on hydrodynamic considerations has been designed by Hunter (1975). This procedure would be appropriate for cases that involve long distances in water bodies with simple configurations. It is inappropriate here because the increase in computation time per point vector would be excessive.

### **Synthesis of Eulerian Data for Trajectory Maps**

The type of trajectory under consideration is a true Lagrangian trajectory—the change in position of a water parcel with time, not the progressive vector diagram sometimes used to analyze current meter records (for example, Johnson and Monahan, 1971; Saunders, 1976) in which a series of calculated vector displacements at the current meter station are serially arranged head-to-tail.

The interpolation of Eulerian data for the desired times,  $t$ , can be accomplished as before. The interpolated data are then used to generate pseudo-Lagrangian displacements. The first displacement will take the imagined water parcel away from the first current meter station. The second and subsequent displacements can be obtained in several ways. One is to spatially interpolate the velocity field as discussed previously. Another is to ensure that the data set contains one point of data for each spatial resolution cell and to use each cell's data for water parcels within the cell until displacements carry the water parcel outside.



Figure 5. Elizabeth River Lagrangian trajectories: computed positions for equal time intervals of 15 minutes, with start time 1400 at southern end of each trajectory (February 10, 1977).

## ATLAS PRODUCTS

Only a portion of the data from earlier and recent Elizabeth River experiments has been reduced. One Lagrangian trajectory map is shown in figure 5. Drifter coordinates were transformed by linear interpolation of raw data to equal time intervals of 15 minutes. Consequently, changes in distance between successive pairs of points can be directly interpreted as changes in tidal-current speeds.

## CONCLUSIONS

A Circulation Atlas incorporating empirical data is under development for the Elizabeth River, Hampton Roads, Virginia. Progress has been made in developing the concept of a Circulation Atlas based on empirical data and in defining methods of data collation and synthesis.

## ACKNOWLEDGMENTS

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## **APPLICATION OF A COMPUTERIZED ENVIRONMENTAL INFORMATION SYSTEM TO MASTER AND SECTOR PLANNING**

**John C. Stewart**

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### **INTRODUCTION**

The Maryland-National Capital Park and Planning Commission (M-NCPPC) has worked with the U.S. Geological Survey (USGS) in the first cooperative effort of its kind to develop a computerized environmental information system to meet the needs of the local planning program.

Several years ago, the USGS recognized the need for producing geologic information that could be used by land-use and environmental planners. Pilot studies have demonstrated a further need for the capability of combining mapped geologic information with other physical and socioeconomic planning parameters. Planners in the M-NCPPC who had reached a similar conclusion welcomed the proposal of a cooperative program to investigate the use of a computer mapping system as an aid to environmental planning. Montgomery County, Maryland, was well-suited as a study area for this cooperative project because of the potential for urban expansion into environmentally sensitive areas and the availability of recently published, planning-oriented geologic information.

Meaningful consideration of the environment in the land-use decision-making process in Montgomery County has been limited because basic environmental data have not been available in suitable format. The planner and decision-maker need an information system that integrates a variety of complex environmental factors in a timely manner. Such a system should provide for varying the factors considered as planning problems change and for weighing the importance of each factor as plan objectives change.

### **PLANNING SETTING**

The Montgomery County Planning Board policy guidelines for Montgomery County land use, transportation, conservation, and open space were established in the adopted General Plan for the Maryland-Washington Regional District. Specific land-use recommendations are included in local area master plans. More detailed sector plans are required to show the location and development schedule of special districts, such as central business districts (CBD) or transit station areas (TSA). Adopted area master plans and sectors plans are incorporated as amendments to the General Plan.

A sector plan was developed for the Shady Grove area because of the special impact anticipated from the projected transit station to be located adjacent to the Baltimore and Ohio Railroad northeast of Redland Road. Special planning emphasis was placed on problems arising from the multitude of public facilities scheduled for the Shady Grove area in general proximity to the transit station. The Shady Grove planning sector was used as a test site to evaluate a computerized environmental information system designed for use by the M-NCPPC.

## **ENVIRONMENTAL INFORMATION SYSTEM**

### **System Design Rationale**

The Montgomery County Composite Mapping System (MCCMS) was designed to provide economical and efficient storage and retrieval of environmental information to planning, primarily in map form, and to provide for combining several types of mapping information to produce synthesis or composite computer maps. Because the system is meant to be used as an operational tool in a planning office, all the manual procedures have been designed to be accomplished by planners and technicians. No familiarity with automatic data processing is required since all planner interaction with the computer is accomplished through a series of formatted questionnaires. When completed, these forms are keypunched to generate a set of control cards for the mapping program, which will produce a map according to the planner's specifications. Data are entered into the system in a similar fashion.

### **How the System Works**

Source maps are first converted to a computer-compatible geographic data base so that they can be processed by the mapping program. Specifications set by the user control the computer mapping and analysis program in processing the stored source maps to retrieve, combine, and analyze the information they contain. The product of this process is a computer-generated map that may show only one factor, such as distribution of surface water, or a combination of several factors. Because the combination or composite map is the product of most interest in planning analysis, its generation and interpretation are discussed in detail in this paper.

### **Sources of Information**

The Montgomery County Environmental Geology Folio provided the geologic information used in the planning system. Released in October 1974, the folio contains five maps with text and tables that describe the nature and distribution of the bedrock, the thickness and physical properties of the various types of unconsolidated surface materials, and the locations of known mineral resources. A recent addition to the folio includes a county slope map with five slope categories. All of this information was plotted on a 1:62,500 scale topographic base map, which also provides surface water information. Elevations were taken from 1:24,000 quadrangle maps. A map showing slope gradient and aspect was also

prepared for the Shady Grove area on a 1:24,000 base map. In addition, existing maps of current land-use, water-sewer service, and aerial photographs with vegetation types delineated were used in the data base.

### Digitizing

To process the source maps with the computer, the mapped information must be converted to numeric form. Fast, economical processing is made possible when this information is stored in small subdivisions of the source map called cells. In a process known as digitizing, a sampling grid is superimposed on the source map, and the address and numeric code for the mapped unit are recorded for each cell (figure 1). These data are put on punch cards for ease in updating and correcting and are stored on magnetic tape for processing. Although the program permits the use of other cell sizes for input, storage, and output, most of the source maps were divided into 18-km<sup>2</sup> (4.5-acre) cells by a latitude-longitude reference system.

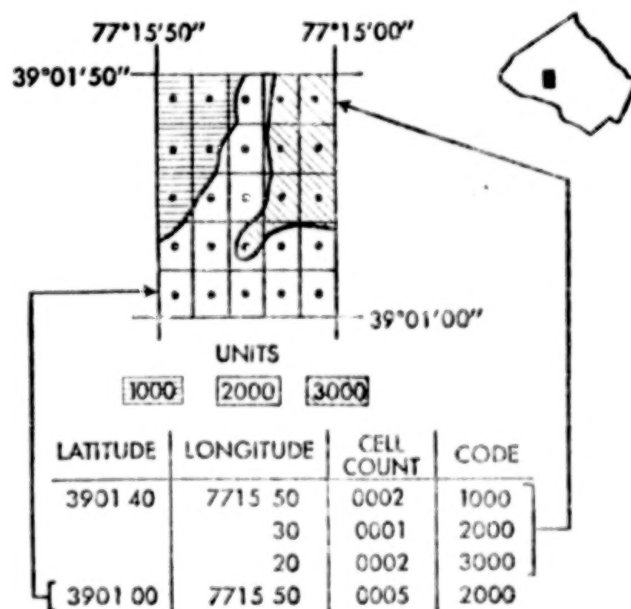


Figure 1. In digitizing, a sampling grid with dots at the center of each cell is superimposed on the source map, and the address and code for the mapped unit are recorded for each cell by scanning from left to right and from top to bottom. To speed up the process, only the first cell of a repeating unit has to be recorded; the rest are taken care of by counting the number of repeat cells. For example, the bottom row requires only one entry for five cells.

### **Use of System For Environmental Analysis**

The goal of the MCCMS with respect to master and sector planning is to provide a rapid and reliable method for analyzing the environmental issues associated with the development of planning areas. This system provides the planner with a convenient tool for planning the effective utilization and conservation of the County's natural resources. The following is a description of the use of the computer system in the environmental analysis of the Shady Grove Sector planning area.

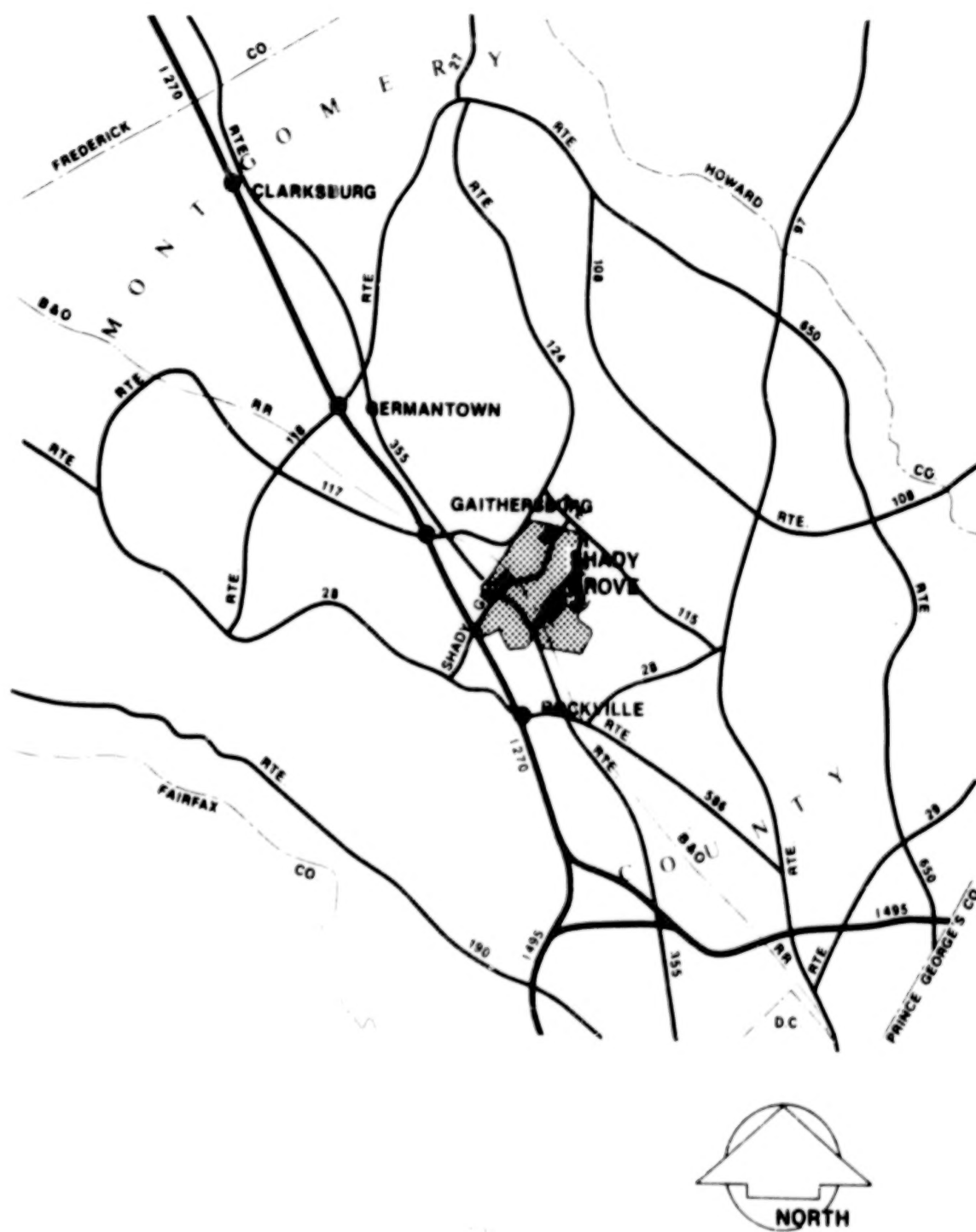
### **Project Description**

The Shady Grove environmental project area encompasses approximately 46,500 km<sup>2</sup> (18 mi<sup>2</sup>). This area is located in the "research corridor" extending north of the National Capital Beltway along Interstate 270 and Maryland Route 355 (figure 2). The general character of Shady Grove is a transition from rural to urban land use and contains a mixture of open-space pasture land, low-density residential development, and recent commercial and industrial development.

The Shady Grove area is encompassed by the Gaithersburg and Vicinity and Upper Rock Creek Master Plans. Because it will be the terminal facility for the Rockville Metro Line, the Shady Grove transit station will serve the geographically large, sparsely populated up-county area north of Rockville. The Shady Grove TSA will maintain a low design profile and will serve a low-density residential commercial and industrial/governmental area. However, the terminal station will require allocation of an extensive area for automobile parking (3000 spaces) because of its large, sparsely populated service area. The terminal transit station will encompass a total of 11,700 km<sup>2</sup> (2900 acres), which is a considerably larger area than those of other transit stations in Montgomery County.

The Shady Grove area is situated entirely within the Piedmont province, a region of rolling upland topography underlain by metamorphic crystalline rocks. The surface elevation ranges from 91 to 150 m (300 to 500 feet) above mean sea level. Large areas of bedrock in this planning sector are covered by a blanket of unconsolidated materials consisting of alluvial stream deposits, artificial fill, and saprolite, which is a product of chemical weathering of the bedrock. This unconsolidated overburden ranges in thickness from 0 to more than 15 m (0 to 50 feet), although bedrock is within 6 m (20 feet) or less of the surface over much of the northern half of the area.

The soils that have developed in this area are generally well-drained. The tree cover is limited to small stands of oak and tulip poplars with some evergreens generally located in stream valleys and areas of shallow bedrock that have not been farmed or otherwise developed.





### **Inventory Phase**

The initial phase of the inventory included an assessment of the basic natural environmental conditions of the area. Through the review of environmental data for the Shady Grove area, a preliminary investigation was made of the spatial significance of the principal natural characteristics of the area. Aerial photographs were also used to determine the location and extent of tree cover.

This preliminary assessment indicated that thickness of overburden, slope, surface water, alluvial deposits, and vegetative cover were probably the most significant natural environmental factors present in the Shady Grove Planning area. A brief description of why each of these environmental factors is significant to the planning process follows.

#### ***Thickness of Overburden***

Significant portions of the planning area have an overburden thickness, or depth to bedrock, of less than 6 m (20 feet). Overburden includes all unconsolidated materials from near the surface down to bedrock. A shallow depth to bedrock could create serious limitations for urbanization, primarily because of increased construction costs. Extensive blasting will be required for large structures that require basements. In addition, the effectiveness of septic tanks could be seriously impaired in areas with thin unconsolidated overburden.

#### ***Slope***

The preliminary investigation also indicated that certain portions of the planning area had steep slopes. Construction on steep slopes, especially over 15 percent, is unwise both economically and environmentally. Placing structures on steep slopes is expensive both in terms of construction costs and improvisation of services such as access roads and utilities. In addition, placing structures in these areas could create serious storm-water problems by disturbing the top soil and natural vegetative cover.

#### ***Surface Water and Alluvial Soils***

Development near surface-water and flood-prone areas should be avoided to prevent loss of life and property. Alluvial soils, although not always within present flood plains, should also be avoided because of potential construction problems and possible septic tank malfunction.

#### ***Vegetative Cover***

Protection of the vegetative cover, especially mature trees, is a primary environmental concern for the Shady Grove area. Because portions of the area have been extensively farmed



and grazed, as well as urbanized, much of the natural tree cover has been lost. It is therefore important to protect scenic beauty and provide a buffer between residential and other land uses. Trees will also aid in preventing air and noise pollution.

### ANALYSIS PHASE

The preliminary evaluation of Shady Grove included the development of single-factor print-out maps of each of the pertinent environmental parameters. The variable-scale option of the mapping program was used to enlarge digitized maps of thickness of overburden, surface materials, and surface water to make these computer maps compatible with the 1:12,000 M-NCPPC base map for the area. Thus, the variable-scale capability of the mapping program permitted easy comparison of data that had previously been manually transferred from smaller scale maps to the 1:12,000 base map.

Because slope and vegetative cover were considered to be significant environmental factors for Shady Grove, source maps were prepared and digitized. In addition, existing land use was digitized to include it in the analysis of the area.

Figures 3 and 4 are sample factor printout maps showing areas of shallow bedrock and mature trees in the Shady Grove area.

A computer composite map was developed (figure 5) to indicate generalized suitability for urbanization, based on environmental considerations. Factors included in the environmental analysis were presence of alluvium, shallow bedrock, surface water, and mature trees. Although this example does not include slope conditions, this factor was considered in later analyses. As indicated in the histogram (figure 6) accompanying the composite map, there are a total of 16 possible factor combinations and a total of 2592 cells in the 46,500 km<sup>2</sup> (18 mi<sup>2</sup>) Shady Grove environmental analysis zone. Each cell measures 5 seconds of latitude by 5 seconds of longitude and covers about 18 km<sup>2</sup> (4.5 acres). Of the total, 1364 cells (52 percent) are now developed or committed, and 1228 (48 percent) are undeveloped. A dark overprint symbol was assigned to developed areas to exclude these cells from further consideration. Statistics for the composite analysis of the undeveloped area are summarized in table 1 and are discussed in the following paragraphs.

In approximately one-half of the undeveloped area (52 percent), none of the four identified environmental factors occur. These areas are indicated as white on the composite map. Assuming that the principal critical environmental parameters have been included in the composite analysis, this indicates that one-half of the undeveloped planning area is suitable for urbanization.

For 35 percent of the undeveloped cells, only one critical environmental factor occurs. The most common factor is shallow bedrock, which occurs as a single limiting condition in

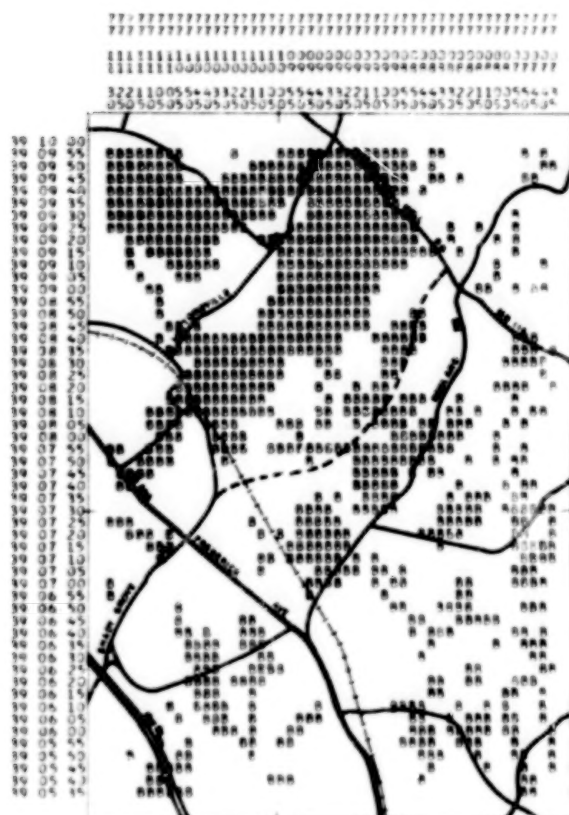


Figure 3. Computer factor map showing shallow bedrock.

28.7 percent of all uncommitted cells. Alluvium, surface water, and mature trees occur as single limiting conditions in the remaining 6.3 percent of the undeveloped area.

If other basic environmental requirements are met (sewerage, storm-water facilities, etc.), the presence of only one critical factor indicates that urbanization in these areas would generally have only a moderate impact upon the environment. However, careful attention should be given to the type of urbanization planned for a given area. For example, the presence of shallow depth to bedrock may have no significant impact upon detached single-family dwellings without basements, but may require extensive bedrock excavation for major structures. Similarly, the presence of mature trees would favor cluster housing and low-density urbanization over large commercial and industrial complexes that usually require extensive areas for structures and parking lots.

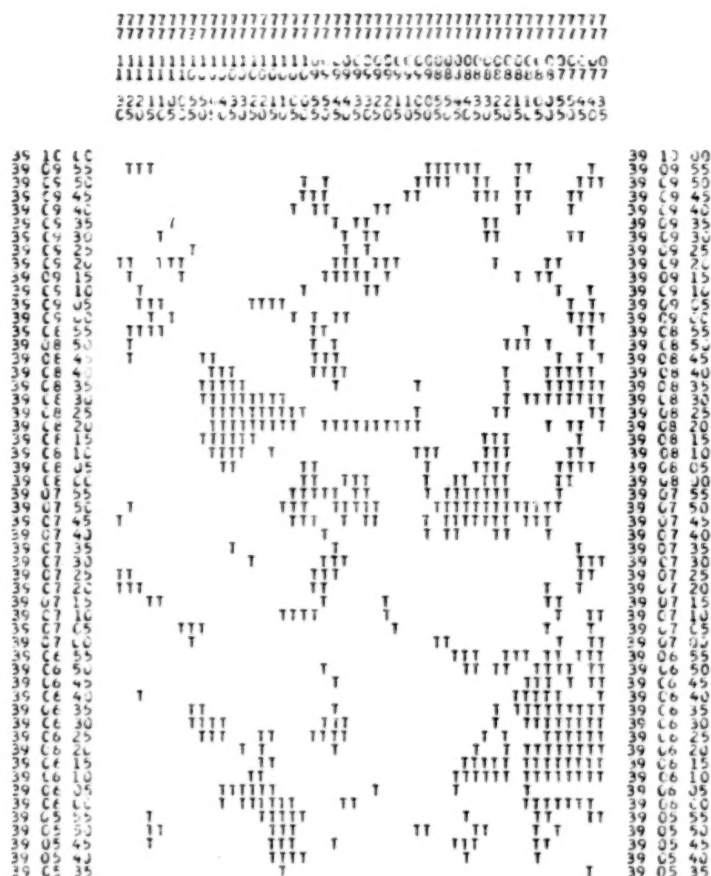


Figure 4. Computer factor map showing mature tree cover.

The remaining 13 percent of the undeveloped land contains cells with multiple critical environmental factors. These include alluvium combining with shallow bedrock (1.3 percent), alluvium with surface water (2.6 percent), and shallow bedrock with surface water (7.6 percent). All other possible combinations total 1.5 percent.

The occurrence of multiple critical factors indicates that development in these areas could have a moderate to severe impact on the environment. Development, especially high-density urbanization, is not recommended in these environmentally sensitive areas. However, if additional urbanization is given as a political or economic reality in sensitive areas, it is desirable that development be clustered on the most suitable land within a cell or group of cells.

#### Comparison of Environmental Analysis With Master Plan

A multicolor transparent master plan overlay was developed for the Shady Grove planning area at a scale of 1:12,000. The master plan transparency was placed over the computer composite map to check for agreement or conflict between recommended environmental



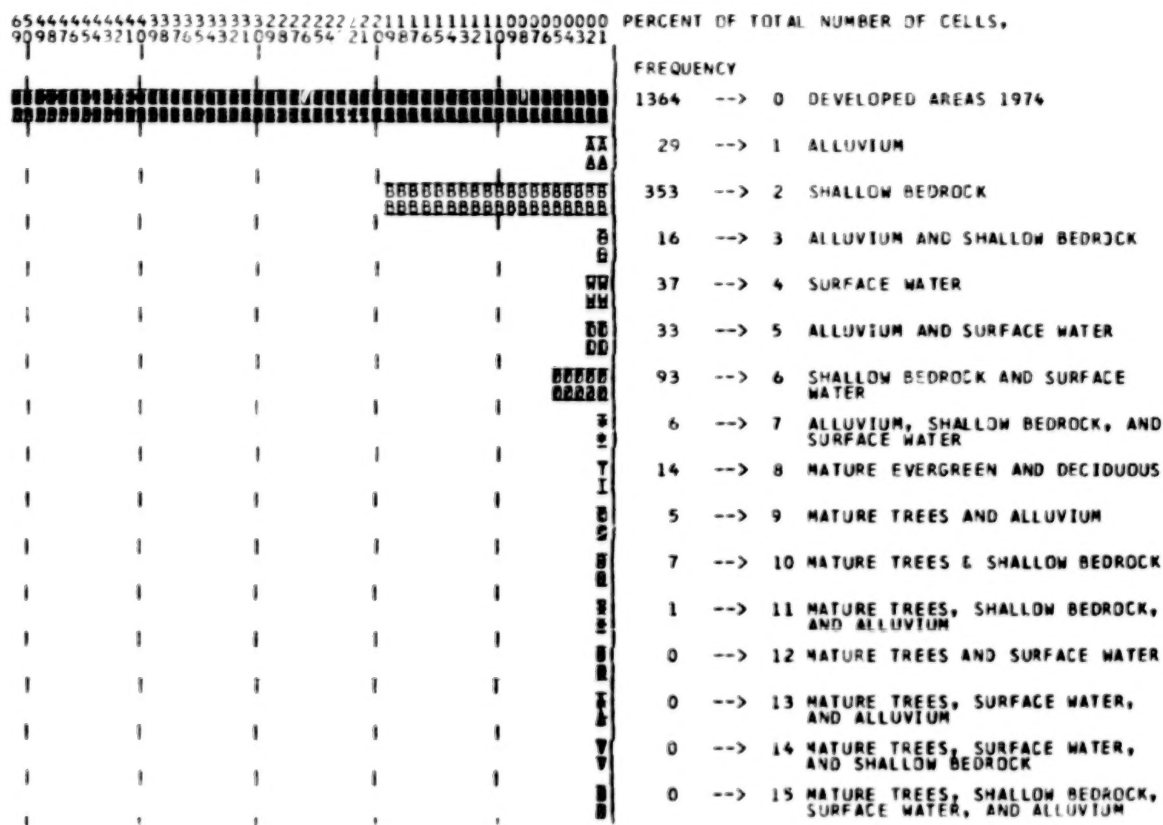


Figure 6. Composite map legend and histogram.

Although the composite map provided a good method for discussing environmental problems associated with general urbanization, it was felt that the environmental analysis of Shady Grove could be expedited by the development of optimization printout maps for various types of specific land uses. Three categories were established: low-density residential (single-family detached), medium-density residential (cluster development), and high-density residential (commercial, industrial, and high-density residential).

### Optimization Maps

The criteria to be established for the various land-use categories was discussed. The analysis flexibility of the system permitted the rapid and inexpensive development of printouts indicating optimal land-use distribution based on specified environmental criteria. The user of the system could readily see changes in the distribution for various land-use classifications as the environmental criteria changed. After testing various alternatives, the environmental criteria for the three land categories were established. Computer printouts were produced

Table 1  
Composite Map Statistics, Undeveloped Area

	Cell Count	Percent
Single Factor		
Alluvium	29	2.3
Shallow bedrock	353	28.7
Surface water	37	3.0
Mature trees	14	1.0
Subtotal	433	35.0
Multiple Factors		
Alluvium and shallow bedrock	16	1.3
Alluvium and surface water	33	2.6
Shallow bedrock and surface water	93	7.6
All others	19	1.5
Subtotal	161	13.0
No factors (white areas on map)	634	52.0
TOTAL	1228	100.0

for each of the three land-use categories, and these composite maps contributed to the development of the Shady Grove Sector Plan.

## SUMMARY

The MCCMS provides a readily accessible geographic data base and a method for compositing and analyzing the mapped information it contains. Because the mapping program has variable input and output capability, entering information into the data base has the effect of making different map scales compatible. This permits the use of information in compositing that previously required extensive drafting.

The major attribute of the program is its capability for combining a series of factors to produce a composite map with statistical information. This map permits convenient spatial

interpretation of interrelated environmental conditions. In addition, by combining factors, the system user can determine the relative importance of each on the basis of their areal extent and frequency of combination with other factors. On an operational level, the system can be used as a forum for discussing and integrating inputs from several Divisions to review planning issues associated with the development of sector and master plans.

The development of the MCCMS and the analysis of the Shady Grove sector afforded the opportunity for the U.S. Geological Survey to work in concert with the M-NCPPC in a unique cooperative effort to develop methods for including environmental considerations in the planning process. The Shady Grove analysis is one example of the use of the MCCMS for long-range planning; other applications of the system will include analyses of critical short-term environmental problems.

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**APPENDIX A**  
**A MULTIDIRECTIONAL COMMUNICATIONS MODEL**

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## APPENDIX A

### A MULTIDIRECTIONAL COMMUNICATIONS MODEL

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#### INTRODUCTION

This paper was prepared by two social scientists: The first author, a social psychologist, served as consultant to the conference/workshop; the second, a geographer, coordinated the program. We list these "credits" because this paper is different from the others in the proceedings. It is not about remote sensing and its use in the Chesapeake Bay Region; rather, it is about how the workshop came to be and the communications processes that influenced its design. We believe that the multicomunications design is relevant for persons in any field who want to bring together people from different work settings, such as scientists, planners, decision makers, and managers.

This paper is divided into three major sections. The introduction contains the background and conference/workshop objectives. The second section describes two conference models. The third describes the planning of the conference, including the roles of the conference coordinators, the steering committee, and the consultant and some examples of the impact of the multidirectional communications model.

#### Background

During the spring of 1976, several persons at the University of Maryland conceived the idea of a conference/workshop to bring together scientists, decision makers, planners, and managers concerned with remote sensing in the Chesapeake Bay region. The following quotes from letters and the proposal on this conference illustrate its goals:

- "... This workshop will include as a major component the immediate use of Landsat data in solving problems currently existent with data and regional planners for the greater Chesapeake Bay region."
- "... the conference has been structured to optimize the dialogue between the *Planners, Enforcement Agencies, Researchers, and Experts in Remote Sensing.*

The conference proceedings will attempt to delineate specific recommendations . . . ."

- "The object of this conference is to focus attention on the value of those sensing techniques involving a variety of (Chesapeake) Bay problems associated with (a) land use development, (b) resources, and (c) pollution."
- "... This workshop will emphasize the problem of the *State and Regional* planners and the restriction placed on them by the existing regulations."

These statements only begin to suggest the complexity of the goals held by its planners. This complexity was compounded by bringing scientists and managers from different agencies together with state and regional planners.

One thing was clear. A workshop that just presented the facts would not do. The need for dialogue between planners, enforcement agencies, management, and research groups was crucial. The principal investigators therefore sought professional advice from a social psychologist for help in designing the program. He supplied some process consultation for the planners and suggested methods for working with groups and designing workshops.

#### *Conference Objectives*

The three objectives of the Chesapeake Bay Remote Sensing Conference were:

- Technical Objective—To update the state-of-the-art of present and potentially usable remote sensing techniques that could be employed in the planning and management of various facets of the Chesapeake Bay estuary.
- Educational Objective—To establish an environment and forum for the exchange of ideas between Bay area managers, planners, decision makers, and remote sensing scientists.
- Planning Objective—To develop and suggest alternatives for use of remote sensing in solving the Chesapeake Bay regional problems.

## **TWO CONFERENCE MODELS**

### **Traditional Workshop/Conference Model**

The design of a traditional conference/workshop for participants with similar backgrounds is well known. Each session consists of a presentation in which the lecturer/listener relationship is established between the speaker and the audience, with a question period following the presentation (figure A-1). Opportunity for interaction between the speaker and listener is usually limited to the question period. A symposium is another example of the traditional

model—a useful design when the information being exchanged is between persons with similar disciplines.



Figure A-1. Traditional workshop/conference model in which the information flow is from the lecturer—the technology expert—to the listener—a technology expert or user who usually has the same disciplinary background as the lecturer.

A similar workshop/conference model is the short course in which the backgrounds of the lecturer and listener are not necessarily similar. This model is useful when a technique, technology, or subject is being introduced to a group of listeners. The only differences from the first model are the complexity of the material in the lecture and the expertise of the listeners. To meet the information sharing goals of the remote sensing conference, all three forms of this traditional model were applicable.

### **The Multidirectional Communications Conference Model**

The multidirectional communications conference/workshop model establishes nontraditional relationships among conference participants. In it the lecturer role is minimized (Pemberton et al., 1974; and Lansky, 1972 and 1976), backgrounds of participants are varied, and information exchange is multidirectional (figure A-2).

Another feature of this second model concerns the planning. When possible, decisions about the program are not made unilaterally, but by a team consisting of representatives from the various groups of participants. In other words, the same model is used for planning as for executing the program.

Experience with this model indicates that the struggles planners have with these notions often mirror the events of the conference/workshop (Pemberton et al., 1974; and Lansky, 1969, 1972, and 1976). Thus, if planners can be sensitive to and manage the concerns and conflicts they have in working with the model, they will experience more success in achieving their goals during the program.

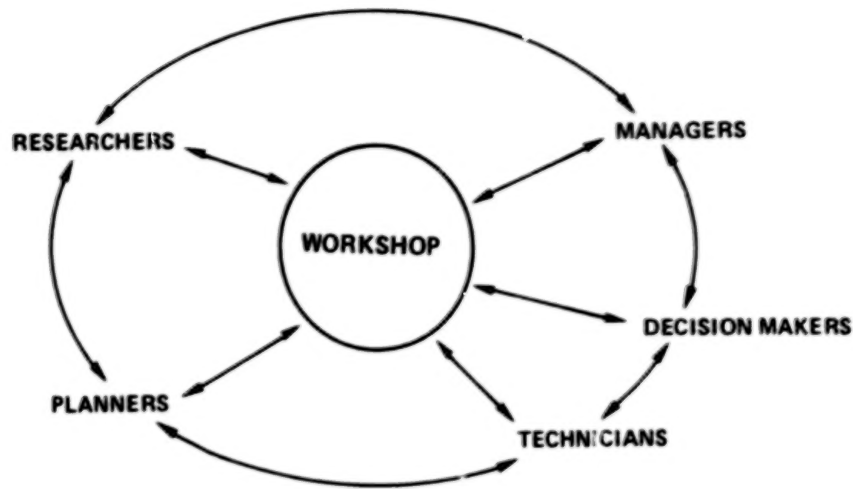


Figure A-2. Multidirectional communications conference model in which the participants of different background exchange information on a subject of mutual interest.

Lastly, advantages of the multidirectional communications model, with special reference to the present program, include:

- It provides an opportunity for establishing communications channels between groups that would not normally get together, but that have a common interest such as the Chesapeake Bay region.
- It provides a forum for airing conflicts both before and during the workshop.
- It provides a forum for conferees to examine issues on an interactive, participatory basis.
- It requires active participation of conferees.
- It provides an incentive for conference planners to identify new groups who are actively involved in the topic so that new dimensions can be added to the effort.

The model's disadvantages include:

- It requires more effort by planners and participants than the traditional models do.
- It requires cooperation between groups and disciplines. For example, scientists must work with managers and planners, rather than talk at them. Physical and social scientists must exchange information and ideas. Traditionally, the former have considered the latter to be weaker sisters. Competing agencies are expected to cooperate in an information and idea exchange.

- It requires tolerance of ambiguity and conflict and the skills for dealing with them. In this model, the speaker/lecturer gives up control of the content and, in part, some processes within each session.

## **PLANNING—A CASE STUDY**

### **Preliminary Phases**

The preliminary discussions led to decisions about timing, location, content, participants, and search for financial support for the workshop. The program coordinator took part in these discussions with the multidirectional model in mind. This orientation affected the planning in several ways. Some of these are described in the following paragraphs; each section contains samples from one facet of the planning process.

### **Role of the Conference Coordinators**

One physical scientist became senior scientist and cochairperson of the conference on a proposal to the National Aeronautics and Space Administration (NASA) to support the program. Another person, a geographer and head of the Inland Environmental Laboratory at the University of Maryland, became principal coordinator (PC). Two other physical scientists joined this pair, making a team of four conference coordinators (CC's). Because of their busy schedules, the four never managed to meet together. Instead, pairs and trios began to put together the program through informal meetings and lengthy telephone conversations.

Dr. Pemberton was selected as PC for several reasons: (1) Her position at the University of Maryland gave her a base from which to carry out and coordinate the plans; (2) Her laboratory is concerned with the issues—overall planning and bringing together disparate resources concerned with the Bay; and (3) She has considerable expertise in educational efforts. Indeed, her special interest in geography is geographic education using the multidirectional model previously described (Pemberton et al., 1974). (4) Lastly, her awareness of the various persons and resources in the Bay region had facilitated the original discussions among the principal investigators and others.

The major outlines of the workshop were agreed upon quite early. The content would focus on three topics: land use, pollution problems, and locating, creating, and managing resources in the Chesapeake Bay region. The beginning was to be more or less ceremonial—greeting the participants, outlining the total workshop, and posing some questions. The middle section would be devoted to sharing information and learning about the various topics from several points of view. The closing sessions would provide final reports of what had gone before, hopefully, with some specific plans for future collaboration among the participants. Lastly, a group of participants would be asked to serve as a steering committee. That committee would take care of publicity, arrangements, selecting and inviting participants, invitations, publications, etc.

Financial support was initially secured from NASA. Thus, in the original plan, most papers would be presented by scientists rather than by users or potential users and planners for the Chesapeake Bay region.

Some issues were controversial. How would the sharing of information and points of view be structured? One view of the middle segment was straightforward. All four CC's were familiar with the traditional conference/workshop model; the PC was very committed to the multidirectional model. Given the objective of facilitating dialogue among scientists, users, and planners from different, often competing, organizations, Dr. Pemberton suggested that the formal sessions include more time for interaction among the participants. The other principal investigators were more than skeptical.

Another problem was how to structure the task-force sessions at the end of the workshop. The goal was clear—a set of documents describing what had occurred, including plans for further work on the issues that had surfaced. Who should head the task forces, how should the topics be selected, what format should be used during the sessions, and what format could be suitable for the documents? These issues had not really been addressed.

The working relationships among the conference coordinators posed yet another set of problems. As already mentioned, all four were overcommitted to other activities. Thus, several misunderstandings arose as to who would do what. The PC had the multidirectional communications model in mind for the planning and the conference; the others did not. In a series of conversations with each CC, the PC suggested that a consultant be asked to meet with the group to work on these matters. Each person independently agreed to have a consultant; however, they were unable to meet before the planning session with the entire steering committee. It was decided to contact the consultant to see if at least three of the CC's could meet with him.

The foregoing is essentially the state of affairs presented to the consultant in mid-October 1976. The problems sounded familiar. When schedules prevent face-to-face meetings, when each person on a team has different ideas about how to proceed, and when each holds a different position in an organization, the difficulties in communicating, dealing with conflicts, and diagnosing and solving problems present a formidable challenge for the group to overcome.

### **Role of the Steering Committee**

Personnel at the Department of Health and Mental Hygiene, the Department of State Planning, and the Department of Natural Resources, who serve on the Interagency Advisory Committee to the University of Maryland Center for Environmental and Estuarine Studies, received copies of the proposal to NASA and the addendum to the Environmental Protection Agency (EPA) for a Conference on the Applications of Remote Sensing to the Chesapeake Bay region, along with a letter that asked each person on the Interagency Committee to designate a person from his agency to serve on a Steering Committee for the workshop.



Thus, the Steering Committee was made up of one representative from each of three Maryland state agencies and two representatives each from NASA and EPA, along with the four principal investigators who wrote the initial proposal, and one person who served as liaison with the Governor's Conference on the Chesapeake Bay.

This committee and its functioning were crucial if the conference was to achieve its goals of commitment to and reexamination of cost-effectiveness technology of remote sensing as applied to Bay problems. To accomplish these objectives, it was planned to have everyone attending the conference take an active role (e.g., delivering a paper, serving on a panel as a respondent, or chairing a session). The function of the steering committee was to suggest conferees and the roles that they might have in the conference. Thus, it would follow that some steering committee members with experience in applications of remote sensing would also be conferees, and others would not. The committee was to offer suggestions about other facets of the design and to help to carry them out.

### Role of the Consultant

So far as we know, there is no unified clear theory about consultation. However, consultants use ideas from here and there to inform their practice. In this instance, interrelated notions about the consultant's role and decision-making were consciously used.

Consultants may take alternative approaches to performing their roles. They may serve as "change agents." In this role, the consultant is an advocate who gives advice, may take over certain activities, and in other ways increase the client's dependency on him. Alternatively, consultants may focus on maintaining and enhancing the autonomy of the client. In this case, the consultant is the disinterested party who intervenes or makes input into the client's interactions but does not decide what he will do. Such interventions are governed by three interrelated processes that the consultant uses and urges his client to use (Argyris, 1970). These are:

- Generating *valid information*, including ideas, hunches, and feelings and attitudes (positive and negative)
- Promoting *free, informed choice* about alternatives based on the information
- Fostering *internal commitment* through the interaction of the previous two processes

In turn, the commitment promotes the generation of valid information, etc. Lastly, as an interventionist, the consultant plays the role of expert (Maier, 1973) by sharing with the client his perceptions of what most likely will lead to what—even if his perceptions do not match those of the client.

Decision-making involves choices between alternatives that will fulfill an objective or goal within the limits imposed by the institution or individuals. Whatever the decision, it can be seen to have two major components: (1) objective quality—some impartial indication of how good the decision is, and (2) acceptance—the extent to which those who must carry out the decision support it. Together, these processes determine the successful performance of the decided upon actions.

These concepts were relevant for several reasons. As a group, the CC's had to decide what design to use for the workshop. Just as the PC could not impose her choice on them, neither could the consultant. In addition, the consultant might already be seen as an "ally" of the PC rather than a consultant to the CC's as a group. Given the press of time, the CC's might go quickly either way—toward a decision to let the PC, and by implication the consultant, have her way, or, without much discussion of the relationship between the activities and their goals, accept the traditional model. If, however, the workshop was to meet the conference goals, the group needed to air the issues that were dividing them so that they could work more effectively together on their program.

### **Planning Sessions—Some Examples**

Examples of what took place at a meeting of the principal investigators and a Steering Committee meeting are presented here to indicate some consequences of employing a multidirectional communications conference model.

#### *Planning Session with the CC's*

At the outset, problems were created when one CC could not attend the initial planning session in which the consultant was to be formally presented to the CC's. The PC and the consultant had discussed the agenda, which included discussing the role of the consultant; spelling out goals, hopes, and concerns for the workshop; sharing ideas on three major segments of the workshop; planning the agenda for the meeting with the Steering Committee; and deciding whether to use the consultant at that meeting and in the workshop.

After the PC briefly reviewed the project, the consultant presented some theoretical notions about his role. He emphasized that he was not there to work for the PC versus the other CC's or Steering Committee members. He accented his disinterest in pushing the participative model for the workshop. If it were to be used, then he might be helpful; if not, his skills in analyzing interactions or the lack thereof could be employed. In short, whether or not he was to work with the team and in what capacity, were, for him, open questions.

After questions and answers about the workshop models, the team began to share its goals. There was considerable hesitancy because of the request for "valid information," and open

statements about "selfish desires." For example, even though there had been public documents about the need for, and interest in, establishing a remote sensing program at the University of Maryland, that topic was introduced reluctantly.

The CC's also expressed several concerns as follows:

- The field of remote sensing is so broad that they despaired of communicating all the new information they wanted to share with one another and with those who knew relatively little about the field.
- The experts, users, and managers whom they had invited were accustomed to getting information. The CC's wanted to meet those expectations.
- The CC's were specifically concerned that the participants not reject the content of remote sensing because of "sociological experiments" with group processes.

The concerns were real. However, one goal was to promote interaction across agency and role lines. Each person hoped that informal get-togethers would provide the opportunity for this interaction. The image was that of a professional meeting at which one attends a few papers but spends more time in informal conversation about professional and other matters. However, in this instance, the program had little "free" time. Furthermore, everyone was expected to attend all meetings.

Also, each person acknowledged that informal meetings were only one way to handle the boredom of having an endless string of lectures. Some revealed that they left the lecture room. Another technique was to "turn the speakers off" and fantasize or read during the papers. Although each person was familiar with these and other techniques, none seemed to be aware of their direct relationship to the structure of most meetings—a series of lectures.

The discussion then moved to specific planning for the sessions. The broad outlines of the opening ceremonial session were easily agreed to. The first content session was more complex. The PC was responsible for organizing it. She wanted to include some method for promoting interaction among the participants after several papers on the present state of remote sensing and data bases for land use. After exploring some alternatives, it was decided to form small groups, each with representatives from the different agencies and occupations. Each group would generate questions for the speakers. A panel of eight speakers would then answer the questions. The design had several advantages:

- It was put together around an interesting topic—questions about the papers—and with persons with different orientations.
- It had potential for revealing some common problems (e.g., some questions might overlap). Perhaps similar questions from different groups would come from persons with the same roles.

- The design itself established a norm of interaction during the sessions.
- If successful, the groupings could be used for other sessions with other tasks.
- Unrealistic expectations would be evident and could be dealt with.

There were also some disadvantages:

- The time spent in the groups would preclude other papers being presented.
- If the questions were similar, that fact would confirm for some the waste of time.
- Bringing together persons from different areas might create conflict on questions or produce answers within the group from those capable of answering them. Not answering might be seen as "playing games," an overriding concern for the CC's.
- Too many questions might be generated, leaving the group dissatisfied with the session.

Again, the concerns were real. Each was looked at as a problem. For example, the presence of too many questions was handled directly. The CC's noted that task forces would be generating and solving new problems. At that time, or during informal get-togethers, questions that were not covered could be examined. The design was finally accepted. However, the consultant read that decision as ambivalent. It came as much from the CC's respect for one another as from conviction about the method. Indeed, the point was made explicitly. Each organizer of a major session, a task given to the CC's, would have the final say about that session.

The consultant's inference turned out to be correct. Only one plan was made about other sessions and participative techniques. The closing phase—task forces on problems—would begin on Thursday afternoon rather than on Friday morning, the last day. By starting earlier, the working teams would not only have more time, but could also "sleep on" their first efforts, which then might be modified during their work on Friday. Although there were no other firm commitments, the other CC's agreed to think about using participative methods during the sessions they were to organize. However, two other decisions were more or less firm. One concerned the list of presenters that contained essentially scientists. The flavor was still that the workshop was for scientists to talk to their peers or to lay their findings on potential users and managers. The consultant was not aware of the impact of this stance until the end of the meeting with the Steering Committee. (See the next section.) The other decision was to invite the consultant to the meeting with the steering committee and, if the steering committee favored a multidirectional communications model, to the workshop itself.

### *Planning Session with the Steering Committee*

The Steering Committee meeting began with general introductions and proceeded through a review of the project, the consultant's role, a reiteration of Steering Committee functions, an overview of the entire program, selection of conference participants, formation of subcommittees, and commitments, responsibilities, and deadlines.

In contrast to the CC's meeting, the consultant did not present his theoretical ideas to the Steering Committee. Rather, he focused on his knowledge of group processes, accepting the fact that he was not to run a sensitivity session, but to identify behaviors that could interfere with the groups' work. He indicated that at times he might become a target when he pointed out things that made others uncomfortable or even angry with him. He received strong backing from one of the CC's who had attended the planning session. The introductory phase continued through the presentation of the opening activities for the conference—the ceremonial and getting acquainted activities mentioned previously. There was strong collaboration, clear focusing on the topics at hand, and flexibility by the CC's and others in listening to and working with alternative strategies. Clear commitments were made about who would contact the opening speakers. The tone was that the group wanted to own the workshop and take responsibility for it.

The next item was the first content session on land use to be organized by the PC. She presented the design and the rationale for it. The group then discussed the sequence she had suggested, particularly the idea of dividing the 65 to 70 participants into small groups to generate questions. There were many objections to this procedure, most of which had been heard the previous week by those at the CC's planning session. Two objections were particularly salient: (1) the loss of information and a chance to be heard by invitees who had important things to say about remote sensing and Chesapeake Bay problems; and (2) the need to use the speakers to answer the questions posed by the conference participants. These topics were related to each other. Clearly, problem solving would be poor if some of the important data were missing. Therefore, more speakers with more points of view were needed on the floor so that the closing part of the morning session could more fruitfully come up with answers to critical questions. Although several persons expressed these views, they were summarized eloquently by one senior scientist/administrator in the group. Many heads nodded assent.

It became obvious that the idea of employing a multidirectional communications model and participative sessions was meeting with a great deal of resistance because of its "unknown" results and the apprehensions expressed by many Steering Committee members. At this point, the consultant intervened. He supported the ideas that had been expressed: (1) the concern about grouping; (2) the need for as much data as possible before problem solving sessions; and (3) the importance of the group's coming up with solutions to, or methods for, working on significant issues. He then called attention to something that the PC had mentioned and that had been in the materials mailed to the Steering Committee before the meeting.



At the end of the conference, the participants were to identify a set of problems and then, during the closing sessions, to work on them. Furthermore, the CC's thought it best to delay the identification of significant issues until all three topics—land use, pollution, and resources of the Chesapeake Bay region—had been discussed. This decision has been made to promote the development of new perspectives in light of the interrelationships among the three topics. To express the idea another way, the consultant suggested that the idea on the floor concerned: (1) the timing of the participative sessions, and (2) how to get data as complete as possible into the final products. Mixed reactions to the proposed participative model were received from members of the Steering Committee. Some liked the potential for something different happening. They saw the PC's design a tactical and strategical idea about sequence. The potential risks were, to them, outweighed by the potential gains in going to a small group activity in light of the goals of the workshop. To avoid being put in the role of defending the participative view, the consultant absented himself during the Committee's discussions because he believed that the decision had to be the Committee's if that decision were to be carried out. The various decisions made during this meeting were:

- To support the PC and the use of a multidirectional communications model
- To extend the workshop by one full day
- To accept the location selected by the CC's
- To eliminate "monitoring personnel" from NASA and replace them with more managers and users from neighboring states
- To invite the consultant to the workshop
- To create subcommittees and a structure for reporting, deadlines, etc.

In addition, the group suggested potential participants to round out the programs. The PC and the other CC's also became aware that most presentations were being made by scientists rather than by users or managers. This arrangement was changed. Lastly, the question of a multidirectional model for the other content sessions remained open.

The meeting appeared to parallel that of the CC's. Some commitment to the multidirectional idea was made: the PC was to go ahead with her plans for the first sessions even though the other two CC's were still hesitant. Indeed, in order to promote information interaction and perhaps to support the two CC's in their hesitancy about the model advocated by the PC, the group decided to add one full day to the program.

## SUMMARY

The planning to use a multidirectional communications workshop/conference model has been presented. Its dynamic nature has been illustrated through the descriptions of the roles of the

CC's, steering committee, and consultant and their interactions with each other. Its chief disadvantage is the amount of effort it requires from all participants. No one—planner or the participant—can sit back and play a passive role; interaction is mandatory. The model's key advantage is its flexibility. It can accommodate any interested group, ranging from scientists to managers, planners, decision-makers, or concerned citizens, which has an interest in and knowledge of common problems such as the Chesapeake Bay region. It therefore enables a multidisciplinary group to come together to examine a problem area from a "systems" approach that encompasses social, political, economic, biological, and technological considerations. However, the model is new and untried in many settings. Thus, it is not surprising that, as in this instance, there is a healthy skepticism about its value and applicability.

That skepticism was evident in the examples presented from the planning of this remote sensing workshop. Using theoretical notions about decision-making and consultation, we have also described how consultation was used to work on specific issues (e.g., resolving conflicts among planners, dealing with uncertainties associated with the new conference methods, and examining the timing and content of specific sessions). The goal of this paper was not to assess the consultation or the workshop, but to expose the readers to the multidirectional communications model.

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\*Between 1968 and 1971, one EPDA conference was held for each of four geographic divisions in the United States for the purpose of improving college teaching of geography. Eight reports from each conference describe the role of the staff, the task of dealing with both content and relationships, and the reaction of participants. For copies of these reports (Broomwood: Salvatore Natoli and/or Clyde Kohn; Asolimar (California): Gary Manson and/or Merrill Ridd; Hueston Woods (Ohio): James Lindberg; Arlie House (Virginia): Dixie Pemberton and/or James Gerdner, write to: John M. Ball, Director, EPDA Institutes for Improvement of College Geography, Department of Geography, Georgia State University, Atlanta, Georgia 30303.

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**APPENDIX B**  
**THE CHESAPEAKE BAY: INTIMATELY VALUED**

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## **APPENDIX B**

### **THE CHESAPEAKE BAY: INTIMATELY VALUED**

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*Chesapeake Biological Laboratory*

*Solomons, Maryland*

I have been asked to speak about the quality of life in the Bay area. My interest is in the effect that personally held values have on Bay health and the resultant quality of life. My work with youth in outdoor education programs over the past 10 years has focused on the development of processes that permit students to become aware of personal values and behaviors that affect the Bay. The principal goals that have evolved from my work include: (1) creating a supportive environment in which the expression of each learner's uniqueness is sought and affirmed, and (2) challenging each person to confront, evaluate, and express personal values about the environments studied. The pursuit of these goals has been a rich and rewarding process for most learners and increasingly enriches my own learning. One technique that I have used effectively to achieve both goals involves modeling the behavior I seek by openly expressing my feelings and personal values. Telling students of my feelings and personal values adds to growth in my knowledge of the quality of life in this region. I intend to share these values as accurately and imaginatively as I can.

My personal conference goals are:

- To use my creative powers to tell others how I value the Chesapeake
- To establish a supportive environment that permits each participant to:
  - Relax and enjoy the material offered
  - Reflect on personal values
  - Find stimulation in response to a challenge to write a statement of personal values
- To follow up on the design by executing *and* submitting seven line drawings that highlight value statements for publication in this Proceedings



Figure 1. Getting oysters with tongs near Benedict, Maryland.



Figure 2. "It's so cold, it would make your blood hum."



Figure 3. Taking oysters in the grand old way.



Figure 4. "Some of these things have modern conveniences."



Figure 5. The pushboat is used on Mondays and Tuesdays to power the sailboats over the rocks.



Figure 6. "Some of those pushboats got so much motor in them, they would sink if they weren't tied on the back."



Figure 7. "It's a fine love affair."

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